UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
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OFFICE OF CHEMICAL SAFETY
AND POLLUTION PREVENTION

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MEMORANDUM

SUBJECT: Revised Benefits of Agricultural Uses of Chlorpyrifos (PC# 059101)

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TABLE OF CONTENTS

Summary

The United States Environmental Protection Agency (EPA) is currently in the process of re-evaluating the risks posed to human health from the use of chlorpyrifos. Chlorpyrifos (0,0-diethyl-0-3,5,6-trichloro-2-pyridyl phosphorothioate) is a broad-spectrum, chlorinated organophosphate (OP) insecticide that has been registered for use in the United States since 1965. Currently registered use sites include a large variety of food crops (including fruit and nut trees, many types of fruits and vegetables, and grain crops), and non-food use settings (e.g., golf course turf, industrial sites, greenhouse and nursery production, sod farms, and wood products). Public health uses include aerial and ground-based fogger mosquito adulticide treatments, containerized ant and roach bait products for residential usage. On average, 8.8 million acres of agricultural crops were treated with chlorpyrifos annually from 2014 – 2018 (Kynetec, 2019).

The timing of the agency's recent regulatory work has been substantially dictated by court-ordered deadlines regarding this insecticide. In 2015, EPA issued risk assessments covering risks to human health posed by dietary exposure to chlorpyrifos. The Agency has revised these risk assessments (US EPA 2020a, 2020b) and is also evaluating the pest management benefits of chlorpyrifos in selected agricultural and non-agricultural use settings. This memorandum provides risk managers within the Agency a high-level assessment of the usage, role and pest management benefits of chlorpyrifos in agricultural settings. The benefits of chlorpyrifos in non-agricultural settings are available in another document (US EPA, 2020c).

Benefits of Chlorpyrifos to Agriculture

The total annual economic benefit of chlorpyrifos to crop production is estimated to be $19 - $130 million. These estimates are based on the additional costs of alternative pest control strategies likely to be used in the absence of chlorpyrifos or reduced revenue for some crops that do not have effective alternatives to chlorpyrifos for some pests. In some cases, effective alternatives could not be found; for those crops, the benefit of chlorpyrifos was estimated by yield or quality losses if chlorpyrifos were no longer available for use.

The high benefits estimate reflects the wide use of chlorpyrifos on many different crops. However, despite the wide use of chlorpyrifos, the majority of the benefits are concentrated on specific crops and regions that rely on chlorpyrifos without available alternatives to control pests. In particular, there are potentially high total costs for some Minnesota and North Dakota sugarbeets, soybeans (nationwide), California oranges, Southeast peaches, and apples (nationwide); the high-end total cost for each of these crops is estimated to be in excess of $7 million per year. High total costs are driven by high per-acre costs in the case of sugarbeets, orange, apple and peach, and by the extent of acres treated in the case of large field crops like soybean despite relatively low costs per acre.

When considering the benefits of chlorpyrifos, some recent developments are important to keep in mind. California is ending almost all agricultural uses of chlorpyrifos by the end of 2020 (CDPR 2019), so high benefits in crops grown in California, reflect past use, rather than benefits that will remain if these uses are still registered nationally in the future. Since 2019, several states, including California, Hawaii, New York, Maryland, and Oregon, have initiated state-level actions to phase out all or most uses of chlorpyrifos.

Chapter 1. Background

The Federal Insecticide Fungicide and Rodenticide Act (FIFRA), Section 3(g), mandates that EPA periodically review the registrations of all pesticides to ensure that they do not pose unreasonable adverse effects to human health and the environment. This periodic review is necessary in order to consider scientific advancements, changes in policy, and changes in use patterns that may alter the conditions underpinning previous registration decisions. In determining whether effects of pesticide use are unreasonable, FIFRA requires that the Agency consider the risks and benefits of any use of the pesticide.

Safety to Human Health

There are inherent risks associated with the use of pesticides, which are substances that are toxic by design. Therefore, EPA imposes requirements on the use of pesticides with the intent to avert unreasonable adverse effects to human health and the environment. However, EPA uses a more stringent standard for dietary risks, which is that food and drinking water exposure will have a reasonable certainty of no harm. The Federal Food, Drug, and Cosmetic Act (FFDCA) defines safe to mean that "there is a reasonable certainty that no harm will result from aggregate exposure to the pesticide chemical residue, including all anticipated dietary exposures and all other exposures for which there is reliable information." This includes exposure through drinking water and all non-occupational exposures (e.g., in residential settings) but does not include occupational exposures to workers.

Under the FFDCA, risks to infants and children are given special consideration. Young children and infants may face greater household exposures because of their behaviors (via combined mouthing and intense play activities) and due to age specific diets. Specifically, pursuant to section 408(b)(2)(C), EPA must assess the risk of the pesticide chemical based on available information concerning the special susceptibility of infants and children to the pesticide chemical residues, including neurological differences between infants and children and adults, and effects of in utero exposure to pesticide chemicals; and available information concerning the cumulative effects on infants and children of such residues and other substances that have a common mechanism of toxicity (21 U.S.C. 346a(b)(2)(C)(i)(II) and (III)).

There are risks to human health from chlorpyrifos exposure. Chlorpyrifos residues can appear in food from crops that were treated with the pesticide, and in drinking water from spray drift or runoff from treated fields. Bystanders and farmworkers can be exposed through application to crops.

Organophosphate insecticides inhibit acetylcholinesterase (AChE), which is an enzyme essential for nervous system function. AChE helps break down the neurotransmitter acetylcholine, and it is essential to the function of the nervous system. When acetylcholinesterase is inhibited, acetylcholine builds up at nerve endings leading to overstimulation of the nervous system. The symptoms of mild acetylcholinesterase inhibition include headache, nausea, dizziness, sweating, and salivation. More severe reactions include muscle twitching and tremors, lack of coordination, vomiting, abdominal cramps, and blurred vision. Very high exposure, such as from an accident, can lead to respiratory paralysis and death (Roberts and Reigart 2016). AChE inhibition has been the health endpoint that EPA has used in risk assessments for chlorpyrifos and setting tolerances for chlorpyrifos (US EPA, 2016).

There is also epidemiological data that reports an association between chlorpyrifos exposure and potential adverse neurodevelopmental effects in infants and children as a result of prenatal exposure to chlorpyrifos (Raugh *et al.* 2006, Rauh *et al.* 2011) or organophosphate pesticide metabolites (Engel et al. 2007, Engel et al. 2011, Young et al. 2005, Eskenazi et al. 2007).

Chlorpyrifos is a widely used pesticide in agricultural settings, with an average of about five million pounds applied annually on about 8.8 million acres (Kynetec, 2019, years 2014 – 2018). There are potential exposures from residues of chlorpyrifos that remain on food when it is eaten. Runoff from agricultural applications can lead to exposure to chlorpyrifos or its metabolites from drinking water. These issues are more fully described in the risk assessment memoranda supporting the Preliminary Interim Decision (PID).

This document replaces an earlier version with incorrect per acre benefit estimates for some crops in Table 2.1-1.

Chapter 2. Estimated Benefits of Chlorpyrifos Agricultural Uses

Section 2.1 Introduction and Summary

This chapter presents the estimates of the total and per-acre benefits of chlorpyrifos in agriculture, based on the costs of alternative pest control strategies likely to be used in the absence of chlorpyrifos. In some cases, effective alternatives could not be found; for those crops the benefits were modeled with yield or quality losses if chlorpyrifos were no longer available for use. The total benefit of chlorpyrifos is estimated to be between $19 and $130 million annually. The high benefit reflects the wide use of chlorpyrifos on many different crops. However, despite the wide use of chlorpyrifos, the majority of the total benefits are concentrated on specific crops and regions that rely on chlorpyrifos without available alternatives to control pests. In particular, there are potentially high benefits for some Minnesota and North Dakota sugarbeets, soybeans nationally, California oranges, Southeast peaches, and apples nationally. The total cost for each of these crops is estimated to be above $7 million per year. High total benefits are driven by high per-acre cost of alternatives in apple and orange, a lack of alternatives leading to potential yield loss in Southeastern peach and Minnesota and North Dakota sugarbeet, and by the extent of acres treated in the case of large field crops like soybean despite relatively low benefits per acre. The large range in cost estimates is due to the differences between the high- and low-cost estimates, mostly for the aforementioned crops.

Section 2 of this chapter describes the methodology used for estimating the benefits of chlorpyrifos. The methodology follows that of previous EPA estimates of the impacts on small businesses (EPA, 2015a). Cost estimates are updated using more recent pesticide usage data, information from the USDA Office of Pest Management Policy, and information obtained through public comments on EPA's small business impact estimates (EPA, 2015a). This analysis was originally performed in 2016, using pesticide usage data from 2010-2014. More recent usage data are now available, and EPA used 2014 – 2018 data to evaluate chlorpyrifos usage in agricultural crops to see if there were significant changes that warranted further analysis. There appeared to be large changes in usage for *Brassica* and sugarbeet; both crops had significant costs in the earlier analysis, so these are revaluated in this document using more recent information. Sorghum was also re-evaluated because of chlorpyrifos use against an emerging invasive pest. Section 3.3 highlights some uncertainties and data limitations in the cost estimates for individual crops. The analysis in this chapter is based on a number of conservative assumptions which are likely to overestimate the actual impacts. For example, the analysis assumes the same pest pressure on every chlorpyrifos treated acre, and the least expensive alternatives are not always chosen as replacements. The analysis also does not account for any changes in cropping patterns and the development of new pesticides or new uses for existing pesticides to fill gaps in pest control without chlorpyrifos.

Table 2.1-1 summarizes the results of the crop-specific assessments for those crops. For most of the crops listed, EPA concludes that there are adequate alternatives to chlorpyrifos to provide control of the pests typically targeted by chlorpyrifos. However, use of alternatives may entail additional control costs to the grower. In some cases, alternatives may not be as efficacious as chlorpyrifos and yield or quality losses may occur. In addition, there do not appear to be adequate alternatives in some crops or regions (e.g., cutworms in Michigan asparagus, borers in

Michigan cherries and Southeast peaches, wireworm in Northern sugarbeets, and symphylans in Oregon strawberries), so for these uses yield losses are estimated.

Table 2.1-1. Benefits of Chlorpyrifos Tolerances, Per-acre and Total Annual Benefits.

Crop	Impact/Acre	Acres Affected	Total Annual Benefit
Alfalfa	$0 - $1	1,029,000	$0 - $1,029,000
Almond [0]	$7 - $35	144,000	$1,009,000 - $5,040,000
Apple [0]	$12 - $51	196,000	$2,346,000 - $9,971,000
Apricot [1]	$7 - $33	100	$1,000 - $4,000
Asparagus, Michigan	$0 - $450	6,000	$0 - $2,569,000
Asparagus, other states [2]	$6 - $20	8,000	$89,000 - $178,000
Beans, succulent [3]	$29	5,000	$137,000
Beans, dry	$0 - $19	6,000	$118,000
Brassica crops[7]			
Broccoli	$8 - $68	6,000	$44,000 - $374,000
Cabbage	$14 – $78	3,000	$42,000 - $234,000
Cauliflower	$11 - $90	200	$2,000 - $18,000
Celery	negligible	100	negligible
Cherry, Sweet	$3 - $65	28,000	$84,000 - $1,811,000
Cherry, Tart	$18 - $201	12,000	$292,000 - $482,000
Corn	$6 - $8	677,000	$4,060,000 - $5,414,000
Cotton, seed treatments	$0 - $9	482,000	$0 - $4,338,000
Cotton, foliar treatments	$0 - $14	126,000	$0 - $1,768,000
Cranberry	$14 - $35	12,000	$174,000 - $434,000
Fig	negligible	negligible	negligible
Garlic	negligible	200	negligible
Grapefruit	$9 - $44	22,000	$202,000 - $987,000
Grape, Raisin	$4 - $30	11,000	$331,000
Grape, Table	$7 - $130	42,000	$293,000 - $5,439,000
Grape, Wine	$4 - $91	23,000	$90,000 - $2,058,000
Hazelnut	$0 - $3	3,000	$0 - $10,000
Lemon	$10 - $290	16,000	$156,000 - $4,526,000
Mint [4]	$19	92,000	$876,000 - $2,582,000
Onion	$11 - $66	58,000	$636,000 - $3,815,000
Orange, California	$8 - $201	39,000	$310,000 - $7,795,000
Orange, Florida	$2 - $33	95,000	$190,000 - $3,134,000
Peach, Georgia and South Carolina	$12 - $430	18,000	$215,000 - $7,703,000
Peach, other states	$8 - $29	11,000	$88,000 – $297,000
Peanut [0,4]	$10	114,000	$1,143,000
Pear	$5 - $37	6,000	$30,000 - $223,000
Peas, succulent	$10 - $370	400	$4,000 - $166,000
Pecan	$1 - $11	115,000	$115,000 - $1,262,000
Pepper	$5 - $10	500	$5,000 - $14,000
Pistachio	negligible	negligible	negligible
Plum/Prune	$7 - $33	3,000	$20,000 - $96,000
Potato	negligible	400	negligible

Crop	Impact/Acre	Acres Affected	Total Annual Benefit
Sorghum[6]	$3 - $4	108,000	$324, 000 - $756,000
Soybean	$1 - $4	3,080,000	$3,080,000 - $12,321,000
Strawberry, Oregon	$6 - $7,813	600	$3,600 - $4,258,000
Strawberry, other states	$10 - $65	11,000	$105,000 - $686,000
Sugarbeet, Minnesota and North Dakota[6]	$13 - $498	60,000	$774,000 - $29,639,000
Sugarbeet, other states[6]	$10 - $13	140,000	$1,403,000 - $1,823,000
Sunflower	$0 - $1	123,000	$0 - $123,000
Sweet Corn[5]	$1 - $3	54,000	$54,000 - $163,000
Tobacco [3]	$4	37,000	$149,000
Tomato[3]	$7	2,000	$11,000
Walnut	$2 - $36	124,000	$248,000 - $4,457,000
Wheat, Spring	$0 - $1	783,000	$0 - $783,000
Wheat, Winter	$0 - $1	549,000	$0 - $549,000
Total		**8,484,000**[7]	**$19,134,000 - $129,675,000**

Sources: EPA estimates of per-acre impacts (Chapter 3.3); average acres treated at least once with chlorpyrifos based on Kynetec, 2016 and 2019 (years: 2010-2014 and 2014-2018, respectively). Figures subject to rounding.

Footnotes:

0 Cost estimates do not account for possible yield losses.

1 Assumes same per-acre cost as for plums/prunes.

2 Range is from $6-10/acre, with some acres treated twice, average of 1.4 applications per affected acre (2010-2014).

3 No range estimated. Limited data suggest only single alternative.

4 No range estimated for per-acre cost. Limited data suggest only a single alternative. No information available on acres treated with chlorpyrifos; range is from 50-100% of the crop.

5 Seed treatment usage data were not available for sweet corn, so the percent of the crop treated is underestimated and thus the per acre cost of revoking the chlorpyrifos tolerance may also be underestimated.

6 Estimates of per-acre impacts are based on Kynetec (2019) usage data from 2014-2018.

7 Estimated total acreage treated from 2014-2018 is 8.8 million acres annually. This estimate in the table is lower because it excludes some crops, is based on usage from 2010-2014 for most of the crops, and because acreage for this table is based on estimates of percent crop treated and harvested acreage (see Section 2.2).

The estimated total cost has a wide range, between $19 and $130 million per year. The midpoint of this range is $74 million. The extremes will have a low probability of occurrence, since all affected acres would have to incur either the lowest or the highest impact. To better characterize the likely benefits for chlorpyrifos, EPA considers three factors.

First, we consider the range of costs for those sites that contribute the most to the total national cost. The average cost for crops with the greatest affected area, such as soybean (3.1 million acres treated with chlorpyrifos), alfalfa (1.0 million acres treated with chlorpyrifos), and cotton (608,000 acres treated with chlorpyrifos), may tend to be at the lower end of the range, since these sites have numerous alternatives from which a grower could choose to replace chlorpyrifos. The estimated range of costs for these crops is relatively small. In contrast, the average cost for crops such as vegetables and fruit in specific areas with important pest problems, is likely to be closer to the upper end of the estimated ranges. For several crops, a range of estimates was not created because of limited alternatives to chlorpyrifos. Some of the highest per-acre crop costs are for *Brassica* crops, which are based on yield loss estimates and information from the original analysis in 2016. This information indicated that there were no feasible registered alternatives, but more recent data suggests growers have largely stopped using chlorpyrifos, indicating the presence of feasible alternatives, as discussed below.

Second, there are several sites for which alternatives may not provide the same level of pest control as chlorpyrifos, but for which estimates of yield loss are not available. Almonds and peanuts are examples, in that estimates of damage caused by borers are not available. Per-acre costs may exceed the upper bound estimate shown in Table 2.1-1, at least on some acres. This factor suggests that total costs would tend toward the upper end of the range.

Finally, another source of variation in the estimated total benefits of chlorpyrifos tolerances is the variability in the number of affected acres. Pest pressure varies from year to year which leads to variation in the number of acres that are treated. Further, as with any input to production, usage may vary according to the cost of the input and the value of the output. Variation in acres treated within individual crops could have substantial impacts on variability in total cost. If, in a given year, there is particularly high pest pressure in a crop with high per-acre impacts, total cost is likely to be relatively high. The converse would lead to a relatively lower total cost. This factor suggests that the range in cost may be wider than shown in Table 2.1-1 in some years, but does not suggest where, over a period of years, costs may fall within the range.

Overall, consideration of these three factors leads EPA to conclude that the total benefits of chlorpyrifos is likely to fall near the midpoint of the range.

Section 2.2 Methodology

To estimate the benefits of chlorpyrifos, EPA has to determine the difference in per acre cost of pest control with and without chlorpyrifos for each crop, multiply that by the acres affected if chlorpyrifos were not available, and sum across crops to find a total. In the equation below, TB is the total benefit of chlorpyrifos, b_i is the estimated per-acre benefit of chlorpyrifos for crop i, and A_i is the average acres in crop i treated with chlorpyrifos:

$$TB = \sum_i b_i \cdot A_i$$

The variable b_i, which we estimate in this chapter for crops treated with chlorpyrifos, should be interpreted as the average per acre benefit of chlorpyrifos for crop i. Multiplying b_i by the average acreage treated with chlorpyrifos in crop i yields the expected benefit for crop i.

The benefits of chlorpyrifos are the difference in per acre cost of production using the identified alternative, plus yield losses if any. To estimate the benefits for each use site ($b_{i,}$), we compare the baseline situation using the per acre cost of production using chlorpyrifos, to a situation where the producer of the crop uses the next best available control strategy, which may mean there are additional pesticide costs or possible yield losses.

There are several steps to estimate of the components of the total benefit equation. First, we identify the acreage treated with chlorpyrifos for each crop to estimate A_i. The second major piece is to estimate b_i. That involves several steps. First, identify the pests targeted with chlorpyrifos in those crops, and then identify reasonable alternative control strategies using registered alternatives to chlorpyrifos, if they exist. After the target pests and alternative control strategies are determined, we estimate the per acre cost of pest control with and without chlorpyrifos; the difference is the per acre benefit of chlorpyrifos, b_i. In most cases, a range of cost estimates are used. The last step is to multiply the per acre incremental benefit for each crop by the acres treated with chlorpyrifos to estimate a total incremental benefit per crop, which are then summed for a total incremental benefit. These estimates represent annual benefits.

Estimating Acreage Treated with Chlorpyrifos

Chlorpyrifos is registered on many crops, but its importance, and therefore the magnitude of impacts, will vary according to the pests that might damage the crop and the registered alternatives available for their control. The percent of a crop that is treated (PCT) can often be an indicator of the importance of a chemical like chlorpyrifos because it is applied at the discretion of the farmer who often is able to scout for the presence of pests before deciding whether to make an application. In particular, low PCT of a chemical often indicates that cost-effective alternatives are available or that pests controlled by the chemical are sporadic or not very damaging and, therefore, the costs in the absence of chlorpyrifos will be negligible.

Market research data from Kynetec (2016, 2019) used for estimating acreage and cost are collected and sold by a private market research firm for the years 1998-2018. Data are collected on pesticide use for about 60 crops by annual surveys of agricultural pesticide users in the continental United States. The survey methodology provides statistically valid results at the state level. To develop the market research data, growers are surveyed about pesticide use on the crops they grow, and they can identify up to three pests they are targeting with a pesticide treatment. To estimate the acres affected by a change to chlorpyrifos registration, we used Market Research Data average number of acres treated from 2010 – 2014 or 2014 - 2018 in the states surveyed divided by the acres grown in those states to estimate the PCT. This PCT is used to extrapolate total treated acreage in the whole country, by multiplying the PCT by national acres harvested reported by the USDA National Agricultural Statistics Survey (Table 2.2-1). This analysis was originally performed using market research data (Kynetec, 2016) for the years 2010 – 2014, but was updated for three crop crops (*Brassica*, sugarbeets, and sorghum) using data (Kynetec, 2019) years from 2014 – 2018 when that data became available. These crops appeared to have significant differences in chlorpyrifos use patterns, and *Brassica* and sugarbeets were also significant contributors to the original high benefit estimates for chlorpyrifos.

Table 2.2-1. Percent Crop Treated with Chlorpyrifos and Acres Harvested.

Crop	Acres Harvested	Percent Treated with Chlorpyrifos	Acres Treated with Chlorpyrifos
Alfalfa	18,375,000	6%	1,029,000
Almond	822,000	18%	144,000
Apple	327,000	60%	196,000
Apricot	11,000	<1%	100
Asparagus, Michigan	10,000	60%	6,000
Asparagus, other states	16,000	50%	8,000
Beans, succulent	269,000	2%	5,000

Crop	Acres Harvested	Percent Treated with Chlorpyrifos	Acres Treated with Chlorpyrifos
Beans, dry	1,533,000	<1%	6,000
Brassica crops			
Broccoli	125,000	4%	6,000
Cabbage	57,000	5%	3,000
Cauliflower	41,000	<1%	200
Celery	29,000	<1%	<100
Cherry, Sweet	87,000	30%	26,000
Cherry, Tart	37,000	32%	12,000
Corn	84,700,000	1%	677,000
Cotton, seed treatment	9,270,000	5%	482,000
Cotton, foliar treatment	9,270,000	1%	126,000
Cranberry	40,000	31%	12,000
Fig	8,000	<1%	<100
Garlic	24,000	1%	200
Grapefruit	73,000	31%	22,000
Grape, Raisin	201,000	6%	11,000
Grape, Table	105,000	40%	42,800
Grape, Wine	592,000	4%	23,000
Hazelnut	29,000	11%	3,000
Lemon	55,000	28%	16,000
Mint[1]	92,000	50-100%	46,000-92,000
Onion	145,000	40%	58,000
Orange, California	177,000	22%	39,000
Orange, Florida	434,000	22%	95,000
Peach, Georgia and South Carolina	26,000	70%	18,000
Peach, other states	84,000	13%	11,000
Peanut	1,260,000	9%	114,000
Pear	52,000	12%	6,000
Peas, succulent	179,000	<1%	400
Pecan	494,000	23%	115,000
Pepper	67,000	1%	500
Pistachio	179,000	<1%	300
Plum/Prune	75,000	4%	3,000
Potato	1,070,000	<1%	400
Sorghum	6,104,000	2%	108,000
Soybean	77,100,000	4%	3,080,000
Strawberry, Oregon	1,900	32%	600
Strawberry, other states	57,000	19%	11,000
Sugarbeet, Minnesota and North Dakota	627,000	28%	140,000
Sugarbeet, other states	498,000	9%	60,000
Sunflower	1,630,000	8%	123,000
Sweet Corn[2]	554,000	10%	54,000

Crop	Acres Harvested	Percent Treated with Chlorpyrifos	Acres Treated with Chlorpyrifos
Tobacco	347,000	11%	37,000
Tomato	372,000	<1%	2,000
Walnut	272,000	46%	124,000
Wheat, Spring	14,000,000	6%	783,000
Wheat, Winter	32,600,000	2%	549,000
Total			**8,484,000**[3]

Sources: USDA NASS, 2010-2014; Kynetec, 2016 (years 2010-2014). For *Brassica*, sorghum and sugarbeet, USDA NASS, 2014-2018; Kynetec, 2019, (2014-2018). Figures are rounded.

Footnotes:

1 No data were available for percent treated. A range of 50 – 100% is used to avoid an underestimate.

2 Percent treated and acres treated with chlorpyrifos do not include use of seed treated with chlorpyrifos.

3 Estimated total acreage treated from 2014-2018 is 8.8 million acres annually. This estimate in the table is lower because it excludes some crops, is based on usage from 2010-2014 for most of the crops, and because acreage for this table is based on estimates of percent crop treated and harvested acreage (see Section 2.2).

In addition to the crops listed in Table 2.2-1, there are other crops that have tolerances for chlorpyrifos. These crops include bananas, cucurbits (cantaloupe, cucumber, pumpkin, squash, and watermelon), rutabaga, sweet potato, and turnips. These crops are relatively small-acreage crops and would typically be grown in combination with other, similar crops, e.g., vegetable growers, fruit and nut growers. The benefits associated with chlorpyrifos are not estimated for these crops, so they are not included in the total.

Estimating the Difference in Cost for Chlorpyrifos Alternatives

EPA identified the primary pests targeted by chlorpyrifos through a review of the chlorpyrifos labels and from private pesticide market research data consisting of the results of marketing surveys of growers (Kynetec 2016, 2019). Growers of about 60 crops are surveyed about pesticide use on the crops they grow, and they are asked to identify the pests they are targeting with a pesticide treatment. The data were queried to identify the major target pests for chlorpyrifos applications (Kynetec 2016, 2019).

EPA identified likely alternatives to the use of chlorpyrifos using biological and economic considerations, which are based on market research data on chemicals targeting the same pests as chlorpyrifos and verified by state extension service pest management recommendations to ensure that they are effective. In some cases, possible alternatives are less expensive than chlorpyrifos, but EPA does not consider these alternatives, at least in isolation. This is based on the assumption that if a less expensive product works as well as chlorpyrifos, the grower would use it. Therefore, it is likely that a less expensive product will not be as efficacious or not used for another reason. In addition, EPA only considered currently registered alternatives to chlorpyrifos. However, existing chemicals can be registered on additional crops and new products can be developed. As a result, estimated impacts to growers may decrease over time.

Some growers, particularly those producing for export market, may be constrained in the choice of alternatives to chlorpyrifos, because maximum residue levels (MRLs) allowed for export crops may not be established for particular chemicals in key international markets, or are set at levels not feasible to achieve. This could be more of an issue for newer chemistries in small acreage fruit and nut crops; establishment of MRLs for minor uses may take time. As a result, some growers may have to use more costly control methods than those identified in EPA's assessment below or forego an export market and potentially receive a lower domestic price for their produce.

For some crops, public comments or the USDA identified pest problems that only applied to specific regions of the country, such as strawberry in Oregon, peaches in the Southeast, and sugarbeets in specific counties in Minnesota and North Dakota. For these crops, additional analysis on costs for those regions is included in the crop-specific cost estimates presented in Section 2.3.

Estimating the Cost of Control with Chlorpyrifos and Alternatives

Market research data provide cost estimates for pesticide applications by crop and pest. Variation in the costs of a pesticide occur due to differences in application rates required for control of pests in each crop. The incremental cost of the rule is estimated as the difference in cost between a chlorpyrifos pest control program and alternative strategies. Differences in insecticide costs were estimated on a per-acre basis. In situations where crops have no alternatives or less efficacious alternatives to chlorpyrifos, yield and/or quality losses were also considered. For some crops, such as cranberry and mint, market research data are not available, and cost and usage estimates were derived from information submitted by the industry or by extrapolating cost information from other crops.

In developing scenarios for the use of alternatives, EPA generally assumes that all target pests are present on each acre treated with chlorpyrifos. Therefore, estimates of additional costs may be based on the use of multiple alternatives to control multiple pests. Data on acres treated by pest, however, indicate that problems with many pests are limited to a portion of the area treated with chlorpyrifos. Thus, estimates involving the use of multiple chemicals to replace a single chlorpyrifos treatment may significantly overestimate impacts. In some cases, such as Michigan asparagus, growers may see yield or quality losses without the ability to use chlorpyrifos. When information on those losses are available, we include yield losses in our estimates of benefits, in some cases extrapolating from one crop to similar crops. In the case of some crops, almonds, for example, there is not sufficient information to estimate quality or yield losses quantitatively.

Section 2.3 Uncertainties

The results of this analysis are subject to uncertainty. This section provides a brief description of the major sources of uncertainty, as well as simplifying assumptions and their implications.

Target Pests

For most crops, EPA identified the primary target pests based on responses of growers to market surveys on the use of pesticides. However, those responses may not fully capture the suite of pests controlled by a broad-spectrum insecticide like chlorpyrifos. Past analyses (*e.g.*, Zalom *et al.* 1999) have shown that broad-spectrum materials such as chlorpyrifos can serve a 'keystone' role in some IPM programs. Removal of such broad-spectrum insecticides from pest management programs can result in unexpected outbreaks of previously minor pests or even the emergence of new pests. As a result, additional control costs could manifest themselves in the short term or develop over time.

Regional Differences

Most of EPA's estimates are national in scope. However, pests and pest pressure may differ across agroclimatic conditions. As a result, the assessment may be missing or underestimating losses in one or more regions of the United States due to differences in target pests and appropriate alternatives. For some crops, EPA was provided with information from crop experts that indicated that regional conditions or pest problems warranted further examination. Additional analysis on regional impacts is included for these crops, which include Michigan asparagus and cherries, Oregon strawberries, Minnesota and North Dakota sugarbeets, and Southeastern peaches. For these areas, the costs were higher than the national estimates for the same crops, but the national estimates would overstate costs in areas with low pest pressure.

New Methods of Insect Control

In this analysis, EPA only considered currently registered alternatives to chlorpyrifos. However, as pesticide markets open through the loss of a control option or new pests emerge, existing chemicals are registered on additional crops or new products are developed. EPA also assumed that growers who use chlorpyrifos will replace it with other insecticides, instead of non-chemical management tactics such as biological control with insect natural enemies. However, some growers may find these approaches to be cost effective over time as understanding of their optimal deployment improves. As a result, estimated impacts to growers may decrease over time.

Intensity of Pest Pressure

In developing scenarios for the use of alternatives, EPA has generally assumed that all target pests are present on all acres treated with chlorpyrifos. Therefore, estimates of additional costs are based on the use of multiple alternatives. Data on acres treated by pest, however, indicate that situations with many pests are limited to a proportion of acres treated with chlorpyrifos. Thus, estimates involving the use of multiple chemicals to replace a single chlorpyrifos treatment may significantly overestimate impacts.

Emerging Pest and Resistance Problems

Most of EPA's cost estimates are based on reported use of chlorpyrifos against specific pests using market research data (Kynetec, 2016) from 2010 – 2014. However, if growers of a crop face relatively new pests or pest problems that are growing in intensity, using historical data on chlorpyrifos use will underestimate any estimate of the cost of alternatives or yield loss at an aggregate level. This may be a particular problem with trunk and limb-boring insects in tree crops, for example, where the potential damage is severe. Currently, most of the affected acreage is in the Southeast, but the pest problem could spread to other areas in the future. In addition, in some crop systems that have only one or two pesticide modes of action registered, the loss of chlorpyrifos may accelerate the evolution of pest resistance against whatever alternative modes of action remain. This could be a result of growers no longer being able to rotate pesticides with different modes of action during seasonal pest management, which is a fundamental resistance management strategy. If resistance develops, unless additional modes of action are registered, the cost impact of chlorpyrifos loss will be higher.

Export Restrictions

EPA identified alternatives to the use of chlorpyrifos based on state recommendations and/or common use as reported in market surveys. However, as mentioned above, some growers may be constrained in the choice of alternatives, particularly those targeting the export market because maximum residue levels (MRLs) may not be established for particular chemicals in key international markets. This could be an issue, especially for small acreage fruit and nut crops for newer chemistries because establishment of MRLs for minor uses may take time. International MRL harmonization is a focus of several ongoing efforts between the Agency and international trade partners but in the short term some growers may have to use more costly control methods than identified in EPA's assessments. However, since EPA frequently based the assessment of impacts on the most expensive likely alternative, any underestimation of costs may be small. Further, small entities may be less likely to target the export market than large growers and those that do target the export market may have higher gross revenue per acre than the average small grower.

Data Limitations

Costs are not estimated for some uses of chlorpyrifos due to data limitations. In particular, there are registered uses of chlorpyrifos as seed treatments that may be important for some crops. However, the extent of impact from loss of chlorpyrifos seed treatments remains uncertain at this time because usage information for seed treatments is not available for chlorpyrifos and alternatives. As a result, this analysis may underestimate the acreage affected by any changes to the registration of chlorpyrifos. Any such underestimation is likely small, however, as the crops for which data are lacking are generally small acreage.

Section 2.4 Crop Benefit Estimates

This section reports estimates of the per-acre benefits of chlorpyrifos for individual crops. Crops are presented in alphabetical order. In most cases, the estimates are made at the national level, but where EPA has found important variation of pests or crop conditions in specific areas, estimates are made by state or region. For some crops, where alternatives may be substantially more costly than chlorpyrifos or there may be a yield and/or quality loss with the use of alternatives to chlorpyrifos, the benefits of chlopyrifos may be quite large. The majority of the estimates are based on reported use of chlorpyrifos against specific pests using market research data from 2010 – 2014, which were the most recently available when the majority of this analysis was initially conducted. More recent usage data (2014 – 2018) were reviewed and suggest that for the majority of crops the situation has not changed and therefore the analysis was not revised. For sugarbeets, sorghum and the *Brassica* crops, the more recent usage data suggests that the situation may have changed, so these crops are reevaluated for that time period below.

Alfalfa
Chlorpyrifos use on alfalfa is primarily targeted at the alfalfa weevil. Although nationally, use of alfalfa is low in terms of percent crop treated, in some states like Kansas, Colorado and

California, growers appear to rely on chlorpyrifos somewhat more heavily. The alternatives consist of synthetic pyrethroids (Table 2.4-1).

Table 2.4-1. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Alfalfa.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Alfalfa	$5	Alfalfa Weevil	Zeta cypermethrin	$4	($1)
			Cyfluthrin	$4	($1)
			Lambda-cyhalothrin[1]	$5	<$1

Source: Kynetec 2016 (years 2010-2014)
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

The alternative scenario to chlorpyrifos ($5/acre) consists of one application of lambda-cyhalothrin ($5/acre) to control alfalfa weevil. This alternative is essentially the same cost as chlorpyrifos, implying costs to the farmer of less than $1 per acre. Gross revenue is $546 per acre, so additional costs are less than 0.2% of gross revenue.

According to market research data (Kynetec 2016; years 2010-2014), just over one million acres of alfalfa are treated annually with chlorpyrifos. With alternatives essentially the same cost or at most one dollar more, EPA estimates the total benefit of chlorpyrifos for alfalfa to be up to one million dollars per year.

Almonds

Chlorpyrifos use on almonds is limited to three applications per year, including dormant/delayed dormant sprays, in-season foliar sprays, and trunk sprays targeting borers. Usage data, however, indicate that growers average 1.25 applications per year. While usage is significant against navel orangeworm and peach twig borer (Kynetec 2016; years 2010-2014), this is due in part to the prevalence of the pests. Numerous alternatives are available for control of these two pests and chlorpyrifos does not rank that highly, relative to these alternatives in terms of acres treated and per university extension recommendations (UC IPM 2014a, b). Substitution of alternatives would be one-for-one with chlorpyrifos.

Emerging pests of concern are leaffooted bugs (at least three species), which have been specifically identified by the almond industry in recent years (Almond Board of California 2015, UC IPM 2012a, Goodhue *et al.* 2019). While the overall average chlorpyrifos usage targeting this pest has been relatively low since 2009 (though sporadically higher in prior years), there was a sharp increase in 2013, and future usage data is likely to reflect a pest of emerging importance. The industry has identified chlorpyrifos as a very important chemical and cites clothianidin as the main effective alternative (Almond Board of California 2015), but usage data indicate that pyrethroids are also being used (Table 2.4-2). At least one recent research article indicates that pyrethroids are the main set of insecticides now used for leaffooted bugs (Daane *et al.* 2019). Extension recommendations also list bifenthrin and esfenvalerate (both pyrethroids) as chlorpyrifos alternatives, but caution against their disruption of beneficial insect populations (UC IPM, 2012a). Because the suitability of the alternatives to chlorpyrifos is questionable, there is the potential for yield/quality losses as well under high pest population pressure in the absence of chlorpyrifos availability. Loss of chlorpyrifos as a leaffooted bug control option may also increase the risk of resistance to pyrethroids developing in pest populations as growers over-use this class of insecticides. If pyrethroids begin to lose effectiveness yield/quality losses would become inevitable.

Table 2.4-2. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Almonds.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Almonds	$17	Navel Orangeworm	Bifenthrin[1]	$12	($5)
			Methoxyfenozide	$24	$7
			Chlorantraniliprole	$31	$14
			Esfenvalerate	$6	($11)
			Lambda-cyhalothrin	$6	($11)
		Peach Twig Borer	Methoxyfenozide	$24	$7
			Esfenvalerate	$6	($11)
			Diflubenzuron	$20	$3
			Lambda-cyhalothrin	$6	($11)
			Chlorantraniliprole	$31	$14
			Bifenthrin[1]	$12	($5)
		Leaffooted Bug	Bifenthrin[1]	$9	($5)
			Esfenvalerate	$6	($11)
			Clothianidin[1]	$16	($1)

Source: Kynetec 2016, 2010-2014.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

Assuming all three pests could be controlled simultaneously with one application of chlorpyrifos ($17/acre), a high-cost alternative scenario would consist of one application of bifenthrin ($12/acre) to control navel orangeworm, one application of methoxyfenozide ($24/acre) to control peach twig borer, and one application of clothianidin ($16/acre) to control leaffooted bug. Together, this strategy would cost approximately $52/acre (total is not exact due to rounding of some costs). This is about $35/acre more than one single application of chlorpyrifos. Average gross revenue is about $6,205 per acre (see Appendix A), implying impacts of about 0.6% of gross revenue per acre, for a total benefit of $5.0 million.

In the absence of the leaffooted bug, growers might apply methoxyfenozide for control of either or both the navel orangeworm and peach twig borer with additional insecticide costs of about $7-14/acre, depending on the number of applications. Methoxyfenozide is highly effective against Lepidoptera (caterpillar pests) but has little to no impact on other insect taxa.

As discussed above, using the alternatives (particularly in regard to controlling leaffooted bugs) might result in yield/quality losses, leading to impacts in addition to chemical cost increase. As a result, almond growers might face additional lost revenue from lower yield or reduced price received for lower quality.

About 144,000 acres of almond are treated with chlorpyrifos each year, on average (Kynetec 2016; years 2010-2014). Additional insecticide costs are estimated to range from $7 to $35 per acre, implying total annual benefits of between $1.0 and $5.0 million, not considering possible yield losses.

Apples

Chlorpyrifos use on apples is limited to one application per year. For airblast applications, only a dormant or delayed dormant spray can be made to the canopy. For post-bloom applications, only trunk applications (to the lower 4 feet of trunk, not to contact fruit or foliage) are permitted. Such trunk applications would be used to target dogwood borers and black stem borers. These are mainly pests in the eastern United States and especially on young or newly planted trees. This is notable, because even though the available usage data shows little usage against borers (Kynetec 2016; years 2010-2014), most applications would only be made to very young trees that have many years of fruit productivity ahead of them. Therefore, while borers contribute little to chlorpyrifos usage in terms of market share or percent of crop treated, the control of borers is important in apple production, and chlorpyrifos is an important tool for this pest. The main alternatives are listed below in Table 2.4-3 and include hand-applied mating disruption dispensers to control dogwood borers. If mating disruption is not effective, as is the case with borers in other tree fruit, then there may be additional yield losses without chlorpyrifos. A comment from Dr. D. Breth of Cornell University stated, in part:

> "In 2013, infestations of [black stem borer] were seen for the first time in commercial apple trees, in multiple western NY sites. In these sites, growers were seeing 30% of trees in parts of their orchards collapsing. To date, at least 30 additional infestation sites have been documented, extending as far as to Long Island." (USDA OPMP, 2017).

While the description shows the seriousness of this pest problem, it does not have enough description of likely affected acreage to allow a detailed economic impact analysis.

In addition to use against the borer pests, pre-bloom dormant or delayed dormant applications on apples would typically target rosy apple aphids, San Jose scale, and overwintering pests including leafrollers, plum curculio, and codling moth. Control of leafrollers, plum curculio, and codling moth is mostly incidental, and growers are unlikely to target these pests specifically during the dormant or delayed-dormant period, but rather, would normally target control tactics for the petal-fall stage, and subsequent foliar sprays. Therefore, EPA does not examine likely alternatives for these pests, since such applications would still be made with or without the availability of chlorpyrifos during the early season.

While petroleum oil is listed as an alternative with a high percentage of crop treated for rosy aphids and San Jose scale, oil is often not an efficacious stand-alone tactic. IPM recommendations call for applications of oil with an insecticide during the dormant/delayed dormant period to target susceptible stages. If this control measure fails for rosy apple aphids, neonicotinoid applications at petal fall can be made to target them (PSU, 2013). For San Jose scale, growers may resort to trying to control the 'crawler' stage later in the growing season using spirotetramat, pyriproxyfen, or pyrethroids (PSU, 2013).

For control of rosy apple aphid and San Jose scale, the alternative active ingredients to chlorpyrifos are projected to substitute one for one with chlorpyrifos. Timing would differ (i.e., chlorpyrifos would go on at delayed dormant, whereas the alternatives would be used at petal fall, targeting different stages of the same pest), but in either case, only one application would be necessary for season-long control. Efficacy is expected to be similar.

As mentioned above, chlorpyrifos use on apples is limited to one application per year. Growers can use it to control borers as a trunk application or the other pests pre-bloom. For the latter situation, a high-cost alternative strategy would be that chlorpyrifos ($14/acre) is replaced by one application of imidacloprid ($6/acre) to control rosy apple aphid/aphid, one application of a tank mix of petroleum oil ($15/acre) and pyriproxyfen ($38) to control San Jose scale/scale (Table 2.4-3). The total cost of the alternative regime is estimated to be $63/acre, which is about $49/acre more expensive than chlorpyrifos (difference may not be exact due to rounding). This is likely to overestimate the cost because chlorpyrifos is already commonly tank-mixed with petroleum oil, but for this analysis it is assumed that chlorpyrifos is applied alone. A low-cost scenario would be an application of acetamiprid to control both pests, with incremental insecticides costs of about $12/acre. For borers, one application of chlorpyrifos being replaced by an application of mating disruption ($65/acre) to control borers, which is about $51/acre more expensive than chlorpyrifos ($14/acre). Average gross revenue is about $8,852 per acre (Appendix A), implying impacts of as much as 0.6% of gross revenue per acre in either scenario. Given an average of 196,000 acres treated annually with chlorpyrifos, total benefits for apples are estimated to range from $2.3 to $10.0 million per year. This may understate benefits if mating disruption cannot control borer pests and if the affected acreage and damage from borers increases over time. Based on Market Research Data from 2010 – 2014, there is little use of chlorpyrifos targeting borers in apples.

Table 2.4-3. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Apples.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Apples	$14	Rosy Apple Aphid/Aphid	Petroleum Oil	$15	$1
			Acetamiprid	$26	$12
			Imidacloprid [1]	$6	($8)
			Lambda-Cyhalothrin	$5	($9)
			Spirotetramat	$46	$32
			Thiamethoxam	$11	($3)
			Esfenvalerate	$5	($9)
		San Jose Scale/Scale	Petroleum Oil [1]	$15	$1
			Pyriproxyfen [1]	$38	$14
			Spirotetramat	$46	$32
			Acetamiprid	$26	$12
			Lambda- Cyhalothrin	$5	($9)
			Imidacloprid	$6	($8)
		Borers/ Dogwood Borers	Mating Disruption [1]	$65	$51

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
[1] Chemicals used to estimate the upper range of cost of control in the absence of chlorpyrifos.

Asparagus

The major pests targeted by chlorpyrifos in asparagus production are shown in Table 2.4-4. Chlorpyrifos labels allow one pre-harvest application and up to two post-harvest ("fern stage") applications per year in this crop. Based on market research data chlorpyrifos is applied 1.4 times per year, on average, to asparagus. Applications are mainly for control of the asparagus aphid in the western U.S., while in Michigan the primary pests are cutworms and asparagus beetle.

Among various aphid pests of asparagus is the European asparagus aphid. While this insect occurs throughout the United States, it appears to be a consistent problem mainly in states west of the Rocky Mountains (Natwick *et al.* 2012, USDA 2003a). According to the University of California (UC), the asparagus aphid causes damage to the plant mainly because its saliva contains toxins that cause distorted growth in the subsequent year that in turn reduces yield. In addition, heavy infestation produces honeydew and may lead to secondary infestation with ants. Major crop damage would occur during this perennial crop's second year (Natwick *et al.* 2012).

Chlorpyrifos is at the top of the University of California's list of insecticides useful in an integrated pest management (IPM) program for the asparagus aphid (Natwick *et al.* 2012), and in California it has been the most-used insecticide for this pest (Kynetec 2016; years 2010 - 2014). Based on University of California recommendations, proprietary pesticide usage data, and EPA's professional judgement, likely alternatives for chlorpyrifos use against this pest would be dimethoate. Dimethoate is a systemic organophosphate (OPs) and thus probably more attractive options than other alternatives for growers (regardless of which region/state is considered). EPA assumes that yield losses with these materials will be unlikely.

The asparagus beetle refers to either of two species, the asparagus beetle or the spotted asparagus beetle. (Natwick *et al.* 2012, USDA 1999a, 2003a). Injury to the plant is by direct feeding on shoot tips; damage is most critical in young stands of plants. For these pests, any one of the leading alternatives (identified by proprietary pesticide usage data and listed in Table 2.4-4) should work as a one-to-one replacement for chlorpyrifos, with no significant changes in yield or quality loss.

Cutworms (several species) damage young asparagus spears as they emerge from the soil surface (USDA 2000b, Natwick *et al.* 2012). Damage often occurs in the spring. Data show some use of carbaryl and permethrin. However, the 2002 Pest Management strategic plan for Michigan asparagus indicated that neither provide control equivalent to chlorpyrifos, and permethrin can fail under some conditions, such as hot weather (USDA 2000b).

Table 2.4-4 shows the difference in cost between the alternatives and chlorpyrifos for the target pests. Use of acetamiprid to control the asparagus aphid would lead to an increase in pesticide costs of $11 per acre, up to $22 per acre if two applications were needed. Average gross revenue is about $3,369 per acre, implying impacts of less than 0.5% of gross revenue per acre. The affected acreage is about 8,100 acres outside Michigan, for an annual benefit of $89,000 to $178,000.

Table 2.4-4. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Asparagus.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Asparagus, other than Michigan	$9	Asparagus Aphid	Acetamiprid[1]	$20	$11
			Dimethoate	$6	($3)
			Malathion	$7	($2)
Asparagus, Michigan	$7	Cutworms	None	25% yield loss	
		Asparagus Beetle	Carbaryl	$7	<$1

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

In Michigan, carbaryl is by far the leading insecticide for the asparagus beetle and is approximately the same cost as chlorpyrifos. Industry experts who commented on the tolerance revocation petition (Bakker, 2016) estimate that yields would be 25% lower with the use of carbaryl or permethrin than with chlorpyrifos. Gross revenue for Michigan asparagus averages $1,800 per acre from 2010 – 2014 (USDA, 2016a), so a 25% yield loss is equivalent to $450 per acre. Costs, therefore, could range from near zero for control of the asparagus beetle to $450 per acre. An average 5,700 acres of asparagus are treated with chlorpyrifos in Michigan (Kynetec 2016; years 2010-2014), so total costs, in terms of lost production, could be as much as $2.6 million per year.

The total benefit of chlorpyrifos or asparagus for the country as a whole is estimated to be $48,500 to $2.7 million per year.

Brassica: broccoli, cabbage, cauliflower

The analysis for broccoli, cabbage and cauliflower was updated more recently than other crops, using usage data from 2014-2018. At the time the original analysis was done, there was substantial use of chlorpyrifos in these crops, but more recent usage data has shown a significant decline in use. Chlorpyrifos applications primarily target cabbage root maggots in *Brassica* crops (Kynetec 2019; years 2014-2018), with over 95% of the chlorpyrifos pounds applied in broccoli and cauliflower and over 70% of the pounds applied in cabbage are targeting root maggots. These pests are in the soil, feed on the roots, and require a soil insecticide application for control. Young plants are more susceptible to damage. For *Brassica* vegetables, it appears that growers can use a diamide insecticide such as cyantraniliprole, the pyrethroid bifenthrin or the neonicotinoid clothianidin to successfully control these pests (UF 2018, Shimat and Zarate 2015).

Table 2.4-5 shows the primary target pest for chlorpyrifos in *Brassica* crops as well as potential alternatives and the difference in cost between the alternatives and chlorpyrifos.

Table 2.4-5. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, *Brassica* crops.

Crop	Cost of Chlorpyrifos ($/Acre)	Target Pest	Alternatives to Chlorpyrifos	Cost of Alternatives	Difference in Cost ($/Acre)
Broccoli	$29	Cabbage Root Maggot	Clothianidin	$21	$8
			Cyantraniliprole[1]	$97	$68
			Bifenthrin	$6	($23)
Cabbage	$12	Cabbage Root Maggot	Clothianidin	$26	$14
			Cyantraniliprole[1]	$90	$78
			Bifenthrin	$4	($8)
Cauliflower	$10	Cabbage Root Maggot	Clothianidin	$21	$11
			Cyantraniliprole[1]	$100	$90
			Bifenthrin	$9	($1)

Source: Kynetec 2019; years 2014-2018. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

The alternative scenario to chlorpyrifos for broccoli, cabbage and cauliflower consists of one application of cyantraniliprole. For broccoli, the baseline treatment of chlorpyrifos costs $29 per acre, and the replacement cyantraniliprole cost $97 per acre, resulting in an increased cost of control of $68 per acre (Table 2.4-5). Average gross revenue in broccoli is about $7,000 per acre, so the increase in cost is just under 1% of gross revenue. According to the available usage data (Kynetec 2019; years 2014-2018), about 5,100 acres of broccoli are treated with chlorpyrifos annually to control root maggots, so the benefit of chlorpyrifos is about $347,000 per year in broccoli.

For cauliflower, the baseline treatment of chlorpyrifos costs $10 per acre, and the alternative scenario of cyantraniliprole costs about $100 per acre, $90 more expensive than the baseline (Table 2.4-5). Average gross revenue in cauliflower is about $9,700 per acre, implying benefits of under 1% of gross revenue per acre. According to the available usage data (Kynetec 2019; years 2014-2018), less than 200 cauliflower acres are treated with chlorpyrifos annually, so the benefit of chlorpyrifos over alternatives is about $9,000 per year.

For cabbage, the baseline treatment of chlorpyrifos costs $12 per acre, and the alternative scenario of cyantraniliprole costs about $90, $78 per acre more expensive than the baseline chlorpyrifos treatment (Table 2.4-5). Average gross revenue in cabbage is about $7,000 per acre, implying benefits of about 1% of gross revenue per acre. According to the available usage data (Kynetec 2019; years 2014-2018), about 2,100 acres are treated with chlorpyrifos annually, so the estimated benefit of chlorpyrifos is about $164,000 per year.

These benefits of chlorpyrifos as estimated above are based on usage data from 2014 – 2018, but chlorpyrifos usage has fallen substantially, with no use reported in three of the last five years for broccoli, and two of the last five years for cauliflower, and in those years, there was substantially less use of chlorpyrifos than in prior years. The estimates here are based on usage over five years (2014 – 2018), so they may not reflect benefits going forward. In addition, California, the primary producer of broccoli and cauliflower, is eliminating the use of chlorpyrifos by the end of 2020 (CDPR, 2019).

Cherries (sweet)

In all cherries, the available pesticide usage data for 2010 to 2014 indicate that an average of 27% of all cherry acreage was treated per year with this insecticide.

The major pests targeted by chlorpyrifos in sweet cherry production are black cherry aphid, San Jose scale, and obliquebanded leafroller. Chlorpyrifos can be phytotoxic to sweet cherry foliage (Pscheidt *et al.*, 2015). Therefore, almost all of its use in sweet cherries occurs before budbreak. EPA also received information (NWHC 2016) about increasing prevalence of grape mealybug problems and the potential issues with lesser peachtree borer, but there did not appear to be much use of chlorpyrifos against these pests (Kynetec 2016; years 2010 – 2014).

Table 2.4-6 shows the primary target pests for chlorpyrifos in sweet cherries, as well as a list of the most likely alternatives to chlorpyrifos for these pests and the difference in cost between the alternatives and chlorpyrifos. As with other crops in this analysis, selection of alternatives was based on recent pesticide usage data (from Market Research Data) as well as extension service guidance and other information. There are less expensive alternatives for black cherry aphid, but EPA concluded that some of these alternatives must be used in combination with each other to get an effect similar to that of chlorpyrifos, such that there would be a modest overall cost increase. If chlorpyrifos was not available for use to control the black cherry aphid, current users would most likely replace one application of chlorpyrifos with one application of petroleum oil plus diazinon and a later in-season application of imidacloprid.

Table 2.4-6. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Sweet Cherries.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Cherries (sweet)	$16	Black Cherry Aphid	Imidacloprid [1]	$7	($9)
			Petroleum Oil [1]	$18	$2
			Diazinon [1]	$21	$5
		San Jose Scale	Petroleum Oil [1]	$18	$2
			Buprofezin	$42	$26
			Pyriproxyfen [1]	$35	$19
		Obliquebanded Leafroller	Chlorantraniliprole	$42	$26
			Spinosad	$34	$18
			Diazinon [1]	$21	$5

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos. Chlorpyrifos is assumed to be mixed with petroleum oil for a total cost of $34/acre. One application of diazinon (mixed with petroleum oil) is estimated to provide control of both black cherry aphid and obliquebanded leafroller.

The likely alternatives for the San Jose scale and obliquebanded leafroller are more expensive. If chlorpyrifos was not available for use to control the San Jose scale, current users would most likely replace one application of chlorpyrifos with one application of a petroleum oil mixed with either buprofezin or pyriproxyfen. These combinations can also be used in the dormant stage but require thorough coverage to be effective (Varela *et al* 2015). For obliquebanded leafroller, extension literature suggests that another organophosphate, such as diazinon, mixed with oil, should provide control during the dormant season that is similar to chlorpyrifos (UC IPM 2015f).

Given the increased cost to control scale, however, sweet cherry growers would experience an increased cost in chemical control as a result of not being able to use chlorpyrifos to control these pests.

For the upper bound impact, EPA assumes that currently, one application of chlorpyrifos per season is used to control all three major pests in sweet cherries: black cherry aphid, San Jose scale, and obliquebanded leafroller. Although there is concern in the industry about grape mealybug and lesser peachtree borer, they do not appear to be significant targets of chlorpyrifos (Kynetec 2016; years 2010 – 2014).

The alternatives scenario consists of one application of chlorpyrifos with petroleum oil ($16 + $18 = $34/acre) being replaced by one application diazinon with petroleum oil ($21 + $18 = $39/acre); this application of diazinon to control black cherry aphid would also control the obliquebanded leafroller. Additionally, EPA estimates growers would make a later, in-season application of imidacloprid ($7/acre) to control the black cherry aphid and one additional application of pyriproxyfen with petroleum oil ($35 + $18 = $53/acre) to control San Jose scale. The baseline scenario of using chlorpyrifos is $34/acre and the cost of the alternative scenario is $99/acre ($39 + $7 + $53). Therefore, the alternative scenario is about $65/acre more expensive than chlorpyrifos (difference may not be exact due to rounding). Average gross revenue for sweet cherry growers is about $9,530/acre (Appendix A), implying benefits of about 0.7% of gross revenue per acre.

The lower bound impact would be replacing chlorpyrifos with diazinon, at an increase in insecticide cost of $5/acre, for control of either black cherry aphid or obliquebanded leafroller. If scale were the only pest problem, the estimated cost would be about $3/acre to use pyriproxyfen instead of chlorpyrifos.

On average, about 26,900 acres of sweet cherry are treated annually with chlorpyrifos. Estimated per-acre increases in insecticide cost imply total benefits of $77,700 to $1.7 million per year for sweet cherry.

Cherries (tart)

According to the available pesticide usage data for recent years (Kynetec 2016; years 2010-2014), the major pests targeted by chlorpyrifos in tart (also called sour) cherry production are green fruitworm and plum curculio. In young orchards, insects that bore into the wood can also be targets of chlorpyrifos use (as a trunk drench) (USDA 2011). However, this use is a minor component in terms of the area of the crop treated with chlorpyrifos, according to the available pesticide usage data used by EPA to identify major target pests (Kynetec 2016; years 2010-2014). Nevertheless, as for other tree fruit crops, EPA acknowledges that borer pest control is a potentially important chlorpyrifos use.

Table 2.4-7 shows the primary target pests for chlorpyrifos in tart cherries, as well as potential alternatives and the difference in cost between the alternatives and chlorpyrifos. There are less expensive alternatives for green fruitworm as a one to one replacement for chlorpyrifos. If chlorpyrifos was not available for use to control this pest, then farmers would likely use esfenvalerate, phosmet, or zeta-cypermethrin. For plum curculio, growers could use phosmet, an organophosphate, or a neonicotinoid, while for borers, phosmet may be an option; the Table 2.4-7 lists the likely pyrethroids and neonicotinoids used by growers. Alternatives are all, on average, lower cost than chlorpyrifos, which suggests that growers using chlorpyrifos face higher pest pressure, multiple pests, or other constraints that make these alternatives less useful than chlorpyrifos. For example, esfenvalerate, one of the cheaper alternatives, can cause outbreaks of mites, so some growers might instead prefer to use chlorpyrifos despite the higher cost.

Table 2.4-7. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Tart Cherries.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Cherries (tart)	$23	Green Fruitworm	Permethrin	$6	($17)
			Esfenvalerate	$5	($18)
			Phosmet [1]	$20	($3)
			Zeta-cypermethrin	$6	($17)
		Plum Curculio	Esfenvalerate	$5	($18)
			Phosmet [1]	$20	($3)
			Thiamethoxam	$18	($5)
		Lesser Peachtree Borer	Phosmet	$20	($3)
			Mating Disruption	$65	$42

Source: Kynetec 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

For this assessment, EPA assumes that one application of chlorpyrifos ($23/acre) is used to control both green fruitworm and plum curculio simultaneously in tart cherries. The alternative scenario consists of one application of phosmet ($20/acre) to control green fruitworm and another application of phosmet ($20/acre) to control plum curculio. The baseline scenario of using chlorpyrifos is $23/acre and the cost of the alternative scenario is $40/acre. Therefore, the alternative scenario is about $17/acre more expensive than chlorpyrifos. Average gross revenue is about $1,695 per acre (Appendix A), implying impacts of about 1.1% of gross revenue per acre. On average, about 13,700 acres of tart cherries are treated with chlorpyrifos.

EPA received comments indicating that borers, particularly the lesser peach tree borer, are not effectively controlled by available insecticides (Korson, 2016). EPA agreed with the conclusion that this pest seems to be a growing problem for which effective alternatives to chlorpyrifos are not available. Michigan extension publications mention that mating disruption is a possible control strategy for lesser peachtree borer, at an additional cost of $42 per acre over chlorpyrifos. There is concern, however, that mating disruption may not be fully effective. For acreage where lesser peachtree borer is uncontrolled, EPA assumes 10% yield loss. This is based on surveys of heavily infested orchards from Michigan Extension experts reported to EPA by the USDA OPMP (USDA OPMP 2017). These surveys indicate that heavily infested orchards have about 20% of trees affected by borers, and half of those are in serious decline, with essentially no yield. The lesser peachtree borer actually reduces lifetime yield and shortens the life of infested trees, but EPA has been unable to find reliable quantitative estimates for yield losses and shortened tree lifetime. The 10% loss estimate may be on the low end, as over time borers could colonize a larger percentage of the trees in an infested orchard. Gross revenue from tart cherries averaged $2,005 per acre from 2010 – 2014, so 10% yield loss would be $201 per acre. An average of 1,389 acres were treated with chlorpyrifos targeting borers in Michigan cherries. This average is from 2012 – 2014, since there were no treatments for borers with chlorpyrifos in 2010 or 2011 according to the available usage data. This is consistent with the lesser peachtree borer emerging as an important pest in Michigan cherries. This estimate is sensitive to the assumptions about yield loss and the share of treated acreage that will suffer those yield losses, and these are a source of substantial uncertainty. This additional cost is specific to Michigan production, and is in addition to the estimate in the previous paragraph, because this cost is specific to Michigan cherry. Cherry production in other regions east of the Rocky Mountains may also have peachtree borer problems sporadically, in which case similar economic impacts would be expected.

The tart cherry low benefits estimate is $291,900, which assumes that 11,800 acres are treated with alternatives for plum curculio and green fruitworm at an additional cost of $17 per acre, and 1,400 acres also are treated with mating disruption for lesser peachtree borer at $65 per acre. The high-end estimate is $481,500 which assumes that 11,800 acres are treated with alternatives for plum curculio and green fruitworm at an additional cost of $17 per acre, and 1,400 suffer 10% yield loss instead of mating disruption for acreage treated for borers acreage. This is based on current chlorpyrifos use patterns against borers and will understate the costs if the problem continues to grow. This estimate is sensitive to the assumptions about yield loss and the share of treated acreage that will suffer those yield losses. These are a source of substantial uncertainty; higher affected acreage or greater yield loss could increase the losses substantially.

Cotton

Chlorpyrifos use on cotton nationally is relatively low – the national average for 2010 to 2014 was about five percent of all acres treated with foliar applications and about one percent treated with seed treatments (Kynetec 2016; years, 2010 - 2014). An average of one application per year was made during those years. There is considerable year to year variation in chlorpyrifos use, likely reflecting fluctuating levels of many insect pests. Use, as measured by percent of the crop treated, is higher in California, at 28% (Kynetec 2016; years, 2010 - 2014).

Chlorpyrifos foliar use in cotton most often targets the cotton aphid, silverleaf whitefly, and stinkbugs (various species). Stinkbugs refers to several species of this type of insect and the importance of one or other individual species varies across the country. Widely distributed members of this complex include the green stinkbug, the brown stinkbug, and the southern green stinkbug. All had historically been relatively minor pests until cotton genetically modified to control insects became widespread (Stevenson and Matcoha 2005, Hebert *et al.* 2009), which reduced application of insecticides targeting other pests. Stinkbugs damage plants by attacking developing cotton bolls directly (UGA 2019).

The cotton aphid and the silverleaf whitefly not only reduce yield by their feeding activity, but also reduce the quality of harvested cotton lint by leaving sticky honeydew on it. Honeydew is the sugary excretion these insects produce from the plant sap they feed on (UC IPM 2015e, MSU 2015). Sticky or discolored lint can result in entire fields' harvests becoming unsaleable not only in the pest-heavy year but in subsequent years, because cotton mills refuse to buy from that area again (UC IPM 2015).

Seed treatments appear to target thrips, although soil pests are often difficult to identify and growers may use seed treatments because they are observed to improve stand establishment, not because of a specific pest problem. Neonicotinoid seed treatments are the most common method for thrips control. At-plant applications of imidacloprid and acephate are also possible control strategies. Aldicarb has not been available for use in cotton in recent years. However, it is registered on cotton, so it may be available for use again in the future.

Based on the available pesticide usage data and extension guidance for pest management, EPA expects that a neonicotinoid seed treatment would be used in place of a chlorpyrifos seed treatment. Dicrotophos or acephate (both organophosphates), in combination with bifenthrin (a synthetic pyrethroid) could substitute for chlorpyrifos for the control of stinkbugs. Likely alternatives for the cotton aphid are imidacloprid, thiamethoxam, or acetamiprid, and for whiteflies, they might include either acetamiprid or pyriproxyfen.

Table 2.4-8. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Cotton.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Cotton, seed treatment	$2	Thrips	Thiamethoxam	$6	$4
			Imidacloprid	$9	$7
			Clothianidin	$11	$9
			Acephate	$2	<$1
Cotton, foliar	$5	Cotton Aphid	Acetamiprid	$11	$6
			Flonicamid	$11	$6
			Imidacloprid	$5	$0
			Thiamethoxam	$6	$1
		Silverleaf Whitefly	Acetamiprid	$11	$6
			Pyriproxyfen	$15	$10
		Stinkbug	Dicrotophos [1]	$4	($1)
			Acephate	$3	($2)
			Bifenthrin	$4	($1)
			Imidacloprid	$5	$0
			Novaluron	$8	$3

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos. An application of chlorpyrifos is assumed to target a single pest, given the sporadic nature of use.

The alternative scenarios depend on the application method and pests; the pests targeted by foliar applications generally appear sporadic in nature and will not frequently occur simultaneously. However, since whiteflies and aphids have been emphasized as particularly damaging to both yield and quality of the harvest (UC IPM 2015), there may be situations where simultaneous control of both pests using two alternative insecticides are needed, at least in California.

For seed treatments, acephate could be used at no increase in costs. Neonicotinoids are more likely, implying an increase in insecticide cost of $4 to $9 per acre. Average gross revenue is about $668 per acre (Appendix A), implying impacts of 0% up to 1.3% of gross revenue per acre. About 482,000 acres of cotton are planted with chlorpyrifos-treated seeds (Kynetec 2016; years, 2010-2014), which implies from $0 to as much as $4.3 million in benefits for chlorpyrifos.

One foliar application of chlorpyrifos ($5/acre) could be replaced with one application of imidacloprid or thiamethoxam at approximately the same cost to control cotton aphid or with acetamiprid ($11/acre). Acetamiprid could also be used to control silverleaf whitefly. One application of dicrotophos and bifenthrin to control stinkbugs would cost about $8/acre in total. Thus, alternative control scenarios for foliar applications cost about the same to $6/acre more than chlorpyrifos. Costs could be up to $19/acre for control of stinkbug with whitefly or aphid together assuming use of acetamiprid; the combination would be about $14/acre more than chlorpyrifos. Average gross revenue is about $668 per acre (Appendix A), implying impacts from 0% up to 2.1% of gross revenue per acre. On average, 126,000 acres of cotton are treated with a foliar application of chlorpyrifos. Total benefit estimates range from almost nothing to as much as $1.8 million per year for replacing foliar chlorpyrifos applications.

Cranberry

Chlorpyrifos is used in cranberry to control lepidopteran (caterpillar) pests and cranberry weevil (Humfeld 2016). Public comments from the cranberry industry indicate that diazinon is an alternative to chlorpyrifos for control of both pests. Chlorantraniliprole is an alternative to control only lepidopteran pests, and cranberry weevil can be controlled with thiamethoxam. According to the industry information, chlorpyrifos treatments in cranberry control both pests with an average cost of $22 per acre, while diazinon treatments cost $36 per acre. Chlorantraniliprole treatments cost $51 per acre (Humfeld, 2016). Industry information did not identify the cost of thiamethoxam, and cranberry is not surveyed in the available market research data. Therefore, EPA estimated the cost of thiamethoxam use by taking the average cost of thiamethoxam used in all available crops in Washington and Wisconsin, the two biggest cranberry producing states (Kynetec 2016, years 2010-2014). The estimated cost of a treatment of thiamethoxam is $6 per acre.

The information on pests, alternatives, and costs is summarized in Table 2.4-9. Currently the cost of control with chlorpyrifos is $22/acre, which provides control of both lepidopterans and cranberry weevil. The alternatives scenario consists of replacing one application of chlorpyrifos with one application of chlorantraniliprole ($51/acre) to control lepidopterans and one application of thiamethoxam ($6) per acre to control cranberry weevil. The scenario is about $35/acre more expensive than chlorpyrifos. If targeting a single pest, the difference in cost between a chlorpyrifos treatment and an alternative treatment for one of the pests will be no more than $29/acre and could be as little as $14/acre with diazinon. Gross revenue averages $7,864 per acre (Appendix A), implying impacts of under 0.5% of gross revenue. According to the Census of Agriculture, there are 40,000 acres of cranberry grown in the United States (USDA 2014); the Cranberry Institute says that 31% of acres are treated with chlorpyrifos, which means about 12,400 acres would be affected. At an additional cost of $14 - $35 per acre, the estimated total benefit to the cranberry industry from chlorpyrifos is $174,000 - $434,000 annually.

Table 2.4-9. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Cranberry.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternative	Cost of Alternative ($/acre)	Difference in Cost ($/acre)

Cranberry	$22	Cutworms	Chlorantraniliprole [1]	$51	$29
			Diazinon	$36	$14
		Cranberry weevil	Thiamethoxam [1]	$6	($16)
			Diazinon	$36	$14

Sources: Cranberry Institute, 2016; Kynetec 2016; years, 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

Grapefruit

In terms of pest management importance, chlorpyrifos is most likely important for control of citrus mealybug in grapefruit. University of Florida extension recommendations (Diepenbrock *et al.* 2019a) indicate that these pests are often controlled by natural enemies. However, when populations get exceedingly large, chlorpyrifos is the most efficacious material, and treatment is warranted "only in cases of severe infestations" (Diepenbrock *et al.* 2019a, b). Mealybugs are difficult to control on citrus due to feeding in concealed locations, such as crevices between foliage and fruit, that are difficult to cover with insecticides applied with airblast sprayers. Spraying is recommended immediately prior to spring flush or periods of peak egg-hatch after the flush (UF, 2012). Given the limited efficacy of alternatives, yield losses could occur under heavy outbreak situations without the use of chlorpyrifos.

While chlorpyrifos usage is reported on grapefruit for control of citrus leafminer and rust mites, it accounts for a minor proportion of all pesticide applications against these pests, with other market leaders surpassing chlorpyrifos in importance. For applications against adult Asian citrus psyllid (mainly in Florida), there are numerous alternatives and growers are currently making use of any and all insecticides at their disposal to contain outbreaks of this pest, which vectors the critical Huanglongbing disease in citrus. Use of chlorpyrifos against red scale is also reported.

EPA's projected upper bound cost scenario consists of one application of chlorpyrifos ($19/acre) per season being replaced by one application of zeta-cypermethrin ($4/acre) to control Asian citrus psyllid; one application of abamectin ($13/acre) to control citrus rust mite/mites; and one application of spirotetramat ($46/acre) to control citrus mealybug. In total, the alternatives would cost about $63/acre, which is about $44/acre more than one application of chlorpyrifos (Table 2.4-10). Lower cost scenarios would occur if only a single pest was to be targeted. For the psyllid, diflubenzuron ($31/acre) or spinetoram ($28/acre) might be used at additional insecticide cost of $9-$12/acre. Alternatives for citrus rust mites or citrus mealybug are $12-$16/acre more expensive than chlorpyrifos. Average gross revenue is about $3,731 per acre, implying impacts of about 1.2% of gross revenue per acre at the upper bound. On average, about 22,400 acres of grapefruit are treated annually with chlorpyrifos (Kynetec 2016; years, 2010-2014). Estimated total benefit for chlorpyrifos ranges from $202,000 to $987,000 per year. As discussed above, in the absence of chlorpyrifos, yield and/or quality losses could occur under heavy outbreaks of citrus mealybug.

Table 2.4-10. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Grapefruit.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Grapefruit	$19	Asian Citrus Psyllid	Zeta-cypermethrin [1]	$4	($15)
			Imidacloprid	$17	($2)
			Abamectin	$13	($6)
			Petroleum Oil	$16	($3)
			Thiamethoxam	$13	($6)
			Diflubenzuron	$31	$12
			Spinetoram	$46	$27
		Citrus Rust Mite/ Mites	Sulfur	$12	($7)
			Abamectin [1]	$13	($6)
			Petroleum Oil	$16	($3)
			Spirodiclofen	$32	$13
			Diflubenzuron	$31	$12
		Citrus Mealybug	Spirotetramat [1]	$46	$27
			Petroleum Oil	$16	($3)
			Imidacloprid	$17	($2)

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

Grapes

In all grapes, the available pesticide usage data indicate that chlorpyrifos was applied once per year on average (Kynetec 2016; years 2010-2014). In table grapes, an average of 41% of the crop was treated; area treated in wine and raisin grapes was much lower (4% and 6%, respectively).

The major pests targeted by chlorpyrifos in table, wine, and raisin grape production are the vine mealybug and the grape mealybug (Kynetec 2016; years 2010-2014). These insects contaminate grape clusters by excreting sticky honeydew that allows black sooty mold, a secondary contaminant, to develop. In addition, these insects can transmit viruses (i.e., grapevine leafroll-associated viruses) that stunt plant growth and reduce yields (UC IPM 2019). Table grapes are particularly vulnerable to mealybug damage because cluster contamination results in buyer rejection. Therefore, treatment for mealybugs in table grapes is recommended at a much lower threshold (about half the mealybug infestation in samples) as compared to wine and raisin grapes.

Table 2.4-11 shows the primary target pests for chlorpyrifos in grapes, as well as likely alternatives and the difference in cost between the alternatives and chlorpyrifos. The alternatives identified for both grape and vine mealybugs are generally more expensive than chlorpyrifos. For vine mealybug, buprofezin or spirotetramat along with a subsequent application of clothianidin are the alternatives likely to be used because of the high degree of control that is probably needed. For grape mealybug, buprofezin or spirotetramat, plus imidacloprid would be the likely option of choice to replace chlorpyrifos. Grape growers would experience an increased cost in chemical control for vine and grape mealybugs as a result of switching to this method and are likely to face some economic losses.

Table 2.4-11. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Table Grapes.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Grapes (raisin)	$18	Mealybug	Imidacloprid [1]	$10	($8)
			Spirotetramat [1]	$48	$30
Grapes (table)	$18	Vine Mealybug	Buprofezin	$25	$7
			Clothianidin [1]	$14	($3)
			Spirotetramat [1]	$54	$36
		Grape Mealybug	Imidacloprid [1]	$26	$7
			Spirotetramat [1]	$54	$36
			Buprofezin	$25	$7
Grapes (wine)	$23	Vine Mealybug	Imidacloprid [1]	$14	($9)
			Buprofezin	$27	$4
			Spirotetramat [1]	$50	$27
		Grape Mealybug	Spinosyn	$36	$13
			Imidacloprid [1]	$14	($9)
			Spirotetramat [1]	$50	$27

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

For raisin grapes, the alternative is to apply spirotetramat, which costs about $30/acre more than chlorpyrifos. Average gross revenue is about $3,942/acre (USDA, 2010 – 2014), implying per-acre impacts of less than one percent of gross revenue. About 11,000 acres of raisin grapes are treated with chlorpyrifos annually (Kynetec 2016; years 2010-2014). The estimate of total benefits from chlorpyrifos are $331,000 per year.

The alternatives scenario for table grapes consists of one application of chlorpyrifos ($18/acre) per season being replaced by one application each of spirotetramat ($54/acre) and clothianidin ($14/acre) to control vine mealybug; and one application each of spirotetramat ($54/acre) and imidacloprid ($26/acre) to control grape mealybug. The baseline scenario of using chlorpyrifos is $18/acre and the cost of the alternative scenario is $148/acre. Therefore, the alternative scenario is about $130/acre more expensive than chlorpyrifos (the difference may not be exact due to rounding). This could overestimate the cost of an alternative control regime because a single application of buprofezin or spirotetramat could potentially control both vine and grape mealybugs with an increase in control cost of $7 to $36 per acre. Average gross revenue is about $11,435 per acre, implying impacts of about 1.1% of gross revenue per acre using the upper bound estimate of per-acre costs. On average, chlorpyrifos is used on 41,800 acres of table grape (Kynetec 2016; years 2010-2014) implying total benefits of $293,000 to $5.4 million annually.

The alternatives scenario for wine grape consists of one application of chlorpyrifos ($23/acre) per season being replaced by one application each of imidacloprid ($14/acre) and spirotetramat ($50/acre) to control vine mealybug and one application each of imidacloprid ($14/acre) and spirotetramat ($36/acre) to control grape mealybug. The baseline scenario of using chlorpyrifos is $23/acre and the cost of the alternative scenario is $114/acre. Therefore, the alternative scenario is about $91/acre more expensive than chlorpyrifos (the difference may not be exact due to rounding). This may overestimate the cost of an alternative control regime if both the vine and grape mealybug can be controlled simultaneously, as is assumed with a single application of chlorpyrifos, with a single application of spirotetramat. Increased costs in the absence of chlorpyrifos could be as low as $4/acre with use of buprofezin to control vine mealybug alone. Average gross revenue is about $4,876/acre (Appendix A), implying impacts of about 1.9% of gross revenue per acre with an increase of $91/acre in control costs. The total benefit of chlorpyrifos is estimated to be between $90,000 and $2.1 million per year, given an average of 22,600 acres of wine grapes treated annually with chlorpyrifos (Kynetec 2016; years 2010-2014).

Hazelnuts

Chlorpyrifos use on hazelnuts (also called filberts) is limited to three applications per year, including dormant/delayed dormant sprays and in-season foliar sprays. Usage data, however, indicates that only about two percent of hazelnut acres are treated more than once. While a large share of chlorpyrifos usage is targeted against the leafroller complex, filbert worms, and filbert aphids, numerous alternatives are available (Wiman and Bell 2020, Pscheidt *et al.* 2015). Imidacloprid, spirotetramat, acetamiprid, and cyfluthrin are all alternatives used for aphids (Table 2.4-12). Diflubenzuron, emamectin, *Bacillus thuringiensis* (*Bt*), methoxyfenozide and spinetoram are recommended alternatives for leafrollers (Wiman and Bell 2020, Pscheidt *et al.* 2015). There is very little reported use of methoxyfenozide, and there is no use of the other alternatives (Kynetec 2016, years 2010-2014). The alternative scenario used is based on alternatives shown to target leafrollers in usage data (Kynetec, 2016; years 2010 -2014).

The alternatives scenario consists of replacing an application of chlorpyrifos ($11/acre) with an application of esfenvalerate ($9/acre) or other synthetic pyrethroid, and an application of imidacloprid ($5/acre) for season-long control of the filbert aphid, leafrollers, and filbert worms. The total cost of the alternative regime is $14/acre, or $3/acre more than using chlorpyrifos alone. Impacts could be negligible, particularly for growers that face a single pest. Gross revenue for hazelnuts averages $3,224/acre (Appendix A), implying impacts per acre well below one percent of gross revenue. On average, about 3,300 acres of hazelnut are treated with chlorpyrifos (Kynetec 2016; years 2010-2014). Total benefits to hazelnut growers could be up to $10,000 per year.

Table 2.4-12. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Hazelnuts.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Hazelnuts	$11	Filbert Aphid	Esfenvalerate [1]	$9	($2)
			Cyfluthrin	$4	($7)
			Imidacloprid [1]	$5	($6)
		Leafrollers Complex	Esfenvalerate [1]	$9	($2)
			Cyfluthrin	$4	($7)
			Imidacloprid [1]	$5	($6)
		Filbert Worm	Esfenvalerate [1]	$9	($2)
			Cyfluthrin	$4	($7)
			Imidacloprid [1]	$5	($6)

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.

1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

Lemons

Chlorpyrifos is used in lemons to control several scale species, citrus bud mite and citrus mealybug. In some parts of Southern California, the soft scale species, citricola scale is controlled naturally (called biocontrol) by parasitic wasps (parasitoids) and is thus rarely a pest. However, in the Central Valley biocontrol is not effective, necessitating broad-spectrum insecticide usage. Petroleum oil can reduce populations as a stand-alone tactic but will not control large outbreaks. UC recommendations state that applications of chlorpyrifos at high rates can control populations for two to three years (UC IPM, 2015b). Alternatives such as neonicotinoids and buprofezin have moderate efficacy but can only control populations for one year. Because citricola scale is mostly susceptible to broad spectrum OP and carbamate applications, outbreaks are therefore most likely to occur in groves that have stopped using such tactics – *i.e.*, it is possible that the impact of this pest will grow over time if chlorpyrifos is removed from the system. In addition to the alternatives listed, UC IPM also recommends acetamiprid for applications in the fall following applications of other neonicotinoids in the spring via soil drench applications (UC IPM, 2015b).

For two armored scale species, California red Scale and yellow Scale, biocontrol is a viable option. UC IPM (2015c) recommends that growers should release rates of 5,000-10,000 parasitoid wasps per acre. Some areas of the state do not see outbreaks due to biocontrol. Applications of chlorpyrifos are timed to correspond with trap captures of the crawler lifestage, and efficacy is very good. Unlike citricola scale, it does not appear that OPs and carbamates confer multiple year suppression, so for comparison with alternatives, it might make more sense to consider one for one substitution of applications. In addition to the listed alternatives in the usage data, UC IPM also recommends buprofezin and carbaryl; each of these would be a one for one substitution with chlorpyrifos. However, if applications are already being made to target citricola scale, it is unlikely that additive applications would be made to also target other scale species.

The citrus bud mite has historically been a pest mainly of coastal-grown lemons but has recently been found on interior regions as well (UC IPM 2019b). Feeding damage distorts developing flower buds which can lead to lower yields and/or reduced fruit quality. While usage data indicate that chlorpyrifos has been used to an appreciable extent to manage this pest, recent extension guidelines from the University of California do not mention this insecticide as an option recommended for use in an IPM program targeting this mite pest. Several alternatives are recommended instead, often mixed with horticultural (petroleum or narrow-range) oils. These include cyantraniliprole in combination with abamectin, fenbutatin oxide, and spirotetramat (UC IPM 2019b).

University of Florida extension recommendations indicate that citrus mealybugs are often controlled by natural enemies, but that when populations get exceedingly large, chlorpyrifos is the most efficacious material and treatment is warranted 'only in cases of severe infestations' (Diepenbrock *et al.* 2019a, b). Mealybugs are difficult to control due to feeding in concealed locations, such as crevices between foliage and fruit that are difficult to cover with insecticides applied by airblast equipment, which is the typical broadcast treatment method for citrus crops. Spraying is recommended immediately prior to spring flush or during periods of peak egg-hatch after the flush (UF 2012). Given limited efficacy of alternatives (Diepenbrock *et al.* 2019b), this pest warrants consideration for yield loss analysis under heavy outbreak situations.

Table 2.4-13 shows the difference in cost between the alternatives and chlorpyrifos for the target pests. Based upon available information for control of citricola scale, one application of chlorpyrifos applied in a given year is assumed to be effective for three years. Thus, the chlorpyrifos cost of $36/acre is divided by three to obtain the annual cost of $12/acre. The alternatives scenario consists of two applications of buprofezin ($176/acre) to control citricola scale each year, and one application of a tank mix of petroleum oil ($35/acre), abamectin ($20/acre), and spirotetramat ($71/acre) to control citrus bud mite and mealybugs. In total, the alternatives would cost about $302/acre (the total is not exact due to rounding), which is about $290/acre more expensive than chlorpyrifos ($12/acre). Citricola scale accounts for about ten percent of the 15,600 acres treated with chlorpyrifos. Red and yellow scale account for over 40% of chlorpyrifos treated acres and mealybugs around 20 to 25%. Use of spirotetramat in place of chlorpyrifos to target red and yellow scale would add about $36/acre to production costs. If only the other scale ("scale complex") were targeted, cost increases might be as low as $10/acre with the use of thiamethoxam. The average gross revenue of lemon is $8,268, implying an impact of about 4% of gross revenue for citricola scale and less than 0.5% for other pests. The total benefit ranges from $156,000 to $4.5 million, but the upper bound assumes all acres are impacted by citricola scale.

Table 2.4-13. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Lemons.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Lemons	$36	Scale Complex [2]	Petroleum Oil	$35	<$1
			Thiamethoxam [1]	$45	$10
			Dimethoate	$22	($13)
		CA Red/Yellow Scale	Petroleum Oil	$35	<$1
			Spirotetramat [1]	$71	$36
			Pyriproxyfen	$63	<$1
		Citricola Scale	Petroleum Oil	$35	<$1
			Buprofezin [1]	$88	$53
			Acetamiprid	$20	($15)
			Dimethoate	$22	($13)
		Citrus Bud Mite	Petroleum Oil [1]	$35	<$1
			Abamectin [1]	$20	($15)
			Spirotetramat [1]	$71	$36
		Citrus Mealybug	Petroleum Oil [1]	$35	<$1
			Imidacloprid	$33	<$1
			Spirotetramat [1]	$71	$36
			Abamectin [1]	$20	($15)

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnotes:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos. Chlorpyrifos is assumed to be used once every three years when used for citricola scale, for an average annual cost of about $12/acre. Buprofezin is expected to be used twice each year to obtain similar control.
2 "Scale complex" does not include red scale and citricola scale

However, as discussed above, using the alternatives might result in yield/quality losses under heavy citrus mealybug outbreak situations, leading to revenue impacts in addition to chemical cost increases.

Mint

Chlorpyrifos is used in mint to control cutworms, mint root borer, and symphylans, according to comments from the Mint Industry Research Council submitted to the chlorpyrifos regulatory docket in 2015 (Salisbury 2015). EPA's earlier Small Business analysis of the petition to revoke chlorpyrifos tolerances (EPA, 2015a) did not include mint. EPA reviewed extension pest management recommendations from states with mint production (e.g., Washington, Oregon, California), and confirmed that the pests mentioned by the mint industry are potentially major problems for the crop. In addition, these recommendations suggested that chlorantraniliprole is an effective alternative for control of two of these pests (cutworms and borers) and that either 1,3-dichloropropene or ethoprop are effective alternatives for symphylan management (UC IPM 2012, Rinehold 2016). Because mint is not surveyed in the market research data that EPA uses to estimate prices, insecticide prices were estimated from national level data on pesticide costs in all crops, averaged from 2010 – 2014 (USDA, 2016b). The cost of chlorpyrifos was estimated at $10 per acre, which may be low for mint if application rates are higher than the national average. Chlorantraniliprole was estimated to cost $29 per acre, for a difference of $19 per acre (Table 2.4-14). If treatment for symphylans is needed, the cost of ethoprop would be about $19 per acre or 1,3-dichloropropene about $166 per acre with a difference in cost of $9 or $156 per acre (Table 2.4-14).

Using information from the USDA on yield and price received for peppermint and spearmint (USDA, 2016b), gross revenue is calculated at $2,080 per acre, implying impacts of 0.9% of gross revenue (Table 2.4-14). According to the Census of Agriculture, there are 92,400 acres of spearmint and peppermint grown in the United States (USDA, 2016b). In the absence of information on the share of the crop treated with chlorpyrifos, we conservatively assume that half to all acreage is treated with chlorpyrifos, and the more expensive alternative chlorantraniliprole would be applied to all the acreage. At an additional cost of $19 per acre for control of cutworms and borers, the estimated total benefits to the mint industry is $876,000 to $1.8 million annually. If the same acreage needed control of symphylans, the estimated total benefits, the additional cost of chlorantraniliprole plus ethoprop is $28, resulting in net benefits for chlorpyrifos of $1.3 to $2.6 million. The actual acreage that needs treatment for symphylans or the other mint pests is unknown.

Table 2.4-14. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Mint.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternative	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Mint	$10	Cutworms, Mint root borer	Chlorantraniliprole [1]	$29	$19
		Symphylans	Ethoprop	$19	$9
			1,3-dichloropropene	$166	$156

Source: Kynetec, 2016; years 2010-2014; Salisbury 2015. Numbers may not add due to rounding.
Footnote:
1 Chemical used to estimate the cost of control in the absence of chlorpyrifos.

Onions

Chlorpyrifos is applied to onions as a soil application at or before planting to control a complex of maggot species, including onion maggots, seedcorn maggots, *etc.*, which are problematic pests nationally, and of particular importance in the eastern U.S.

Seed treatments with neonicotinoids, spinosad, and cyromazine are available with demonstrated efficacy (Hoepting and Nault, 2012). Neonicotinoid-treated seeds are known to be used and are effective in controlling the soil pest complex, including maggots. Since seed treatments are done before planting, a grower could save the costs of actual application for chlorpyrifos pre-plant applications, *i.e.*, one less trip across the field. In the absence of seed treatments, preliminary indications are that maggot efficacy of chlorpyrifos is superior to alternatives (SEVEW 2019), so a yield loss might occur where neonicotinoid seed treatments are not viable or available. Applications of lambda-cyhalothrin and diazinon can be substituted one-for one with chlorpyrifos, but efficacy against the maggot complex is unclear.

Based upon available information on use, cost, and efficacy, EPA projects that the most likely alternative scenario to the use of chlorpyrifos is a seed treatment that costs from $20 to $75 per acre (Utah State University, Cooperative Extension, 2011). Due to variability in available packages (*i.e.*, some seed treatment systems are only available as a package treatment that also includes fungicides), pricing for this option is difficult to estimate. Using the upper bound of this range to estimate the impact, the alternatives scenario would cost $66/acre more than the current use of chlorpyrifos ($9/acre). Average gross revenue for onions is approximately $6,322 per acre, implying an impact of about 1% of gross revenue per acre. A low-cost estimate would be about $11/acre more for an application of diazinon instead of chlorpyrifos (Table 2.4-15). About 57,800 acres of onion are treated each year with chlorpyrifos, on average (Kynetec 2016; years 2010-2014). Total benefit for chlorpyrifos is estimated to be $636,000 to $3.8 million per year.

Table 2.4-15. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Onions.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Onions	$9	Maggot Complex (onion, seed, etc.)	Lambda-cyhalothrin	$5	($4)
			Diazinon [1]	$20	$11
			Spinetoram	$39	$30

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos. Data on seed treatment price from Utah State University, Cooperative Extension (2011).

Oranges (California)

The analysis for oranges was done separately for California and Florida due to significant differences in production practices and target pests for chlorpyrifos. California citrus production is driven by the sale of fresh produce, in contrast with Florida which mainly grows oranges for juice. California also has unique pest control challenges with citricola scale and katydids, which are not an issue for Florida growers. These considerations justify analyzing California oranges separately from Florida oranges. In addition, comments received on the tolerance revocation suggest that California growers need to control a complex of ant species frequently; no similar comments were received from Florida growers or crop experts (Grafton-Cardwell 2015, Morse 2015).

In some parts of Southern California, citricola scale is under biocontrol by parasitoids and is rarely a pest. In the Central Valley, however, biocontrol is not effective which necessitates broad-spectrum insecticide usage. Petroleum oil can reduce populations as a stand-alone tactic but will not control large outbreaks. UC recommendations state that applications of chlorpyrifos at high rates can effectively control or "re-set" populations for two to three years (UC IPM, 2015b). Alternatives such as neonicotinoids and buprofezin have moderate efficacy but can only control populations for one season. Each often requires more than one application per year. Because citricola scale is usually controlled with broad spectrum organophosphate and carbamate applications, outbreaks are most likely to occur in groves that have recently stopped using such tactics—i.e., it is possible that the impact of this pest will grow over time if chlorpyrifos is removed from the system. Certain ant species, such as the Argentine ant, tend to and protect phloem-feeding insects, such as citricola scale, in order to feed on the phloem-feeders' sugary honeydew excretions. If ant control is diminished with the use of alternatives, this scale-tending behavior would also contribute to an increase in scale populations and their damage to the crop. However, the cost estimates below are based on controlling pests that are tended by ants, not direct ant control. In addition to the alternatives listed, UC IPM also recommends acetamiprid for applications in the fall following applications of other neonicotinoids in the spring via soil drench applications for citricola scale (UC IPM, 2015b). As a result, an upper bound alternatives scenario could be two to four applications of acetamiprid plus two to four applications of imidacloprid as a soil drench, or two to four applications of buprofezin plus petroleum oil.

For two armored scale species, California red scale and yellow Scale, biocontrol is a viable option. UC IPM (2015c) recommends that growers should release parasitoid wasps at rates of 5,000-10,000 per acre. Some areas of the state do not see outbreaks of these scale species due to biocontrol. In groves where insecticide treatments are required, applications of chlorpyrifos are timed to correspond with trap captures of crawlers (immature scale) and efficacy is very good. Unlike citricola scale, it does not appear that organophosphates and carbamates confer multiple year suppression for California red scale. In addition to the listed alternatives in the usage data, UC IPM (2015c) also recommends buprofezin and carbaryl; each of these would also be a one for one substitution with chlorpyrifos. However, in years where applications are already being made to target citricola scale, it is unlikely that additive applications would be made to also target other scale.

Katydids are a significant pest problem in the absence of broad-spectrum pesticide options. Katydids (e.g., forktailed bush katydid) feed directly on fruit after petal fall, leading to either fruit drop or quality loss from scar tissue formation. Since California is a primarily fresh market producer, such quality losses would be significant. Beyond the listed insecticides in Table 2.4-16, diflubenzuron and naled are additional materials recommended for katydid control and would likely be used as a one for one substitution for chlorpyrifos (UC IPM, 2015d). On average, these chemicals cost just over $20/acre (Kynetec 2016; years 2010-2014).

Table 2.4-16. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, California Oranges.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Oranges (CA)	$43	Citricola Scale	Petroleum Oil	$21	($22)
			Pyriproxyfen	$74	$31
			Acetamiprid	$61	$18
			Dimethoate	$14	($29)
			Buprofezin [1]	$93	$50
		CA Red/Yellow Scale	Petroleum Oil	$21	($22)
			Pyriproxyfen	$74	$31
			Spirotetramat	$65	$22
			Imidacloprid	$29	($14)
			Buprofezin [1]	$93	$50
			Acetamiprid	$61	$18
	$17	Katydids	Cyfluthrin	$9	($8)
			Fenpropathrin	$25	$18
			Cryolite [1]	$46	$29
			Chlorantraniliprole	$33	$16
			Dimethoate	$11	($6)

Source: Kynetec, 2016; years 2010-2014.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos. Chlorpyrifos is assumed to be used once every three years against scale, for an average annual cost of about $14/acre. Buprofezin is expected to be used twice each year.

Two applications of chlorpyrifos per year are permitted on California oranges. In practice, about 13% of acres are treated more than once. Based upon available information for control of scale insects, one application of chlorpyrifos applied in a given year is conservatively assumed to be effective for three years. Thus, the chlorpyrifos cost of $43/acre is divided by three to obtain the annual cost of about $14/acre. This might be replaced by two applications of buprofezin annually ($186/acre) for an increase in insecticide costs of $172/acre. For an application of chlorpyrifos to control katydids at about $17/acre, alternatives range in price from $25/acre for fenpropathrin to $46/acre for an application of cryolite, that is, $8 to $29/acre more than chlorpyrifos. An upper bound estimate of cost would be for an acre treated for both scales and katydids for a total increase in insecticide cost of $180 to $201 per acre. Average gross revenue is about $4,278 per acre, implying impacts of less than 0.5% to as much as 4.5% of gross revenue per acre. According to market research data (Kynetec 2016; years 2010-2014), 38,800 acres of oranges are treated, on average. Total benefits, therefore, are estimated to range from $310,000 to about $7.8 million per year.

However, in addition to being more expensive than chlorpyrifos, these alternative chemicals may also be less efficacious, leading to potential yield and/or quality losses for citricola scale.

Oranges, Florida

Florida orange production is driven by the processing (juice) market, in contrast with California, which mainly grows oranges for the fresh market. While chlorpyrifos usage is reported on Florida oranges for control of rust mites, it accounts for a minor proportion of all pesticide applications against these pests, with other market leaders far surpassing chlorpyrifos in importance. For applications against adult Asian citrus psyllids, there are numerous alternatives and growers are making use of any and all insecticides at their disposal to suppress outbreaks of this pest, which vectors the critical Huanglongbing disease in citrus.

EPA's alternative scenario consists of one application of chlorpyrifos ($13/acre) per season being replaced by one application of zeta-cypermethrin ($5/acre) to control Asian citrus psyllid and one application of a tank-mix of petroleum oil ($15/acre) and abamectin ($13/acre) to control citrus rust mites. In total, the alternatives would cost about $33/acre (the total is not exact due to rounding), which would be about $20/acre more expensive than one application of chlorpyrifos (Table 2.4-17). This may be an overestimate of cost because more than one application of chlorpyrifos may be needed to target multiple pests and here EPA assumes only one. A lower bound estimate would be applications of either imidacloprid or thiamethoxam to target either Asian citrus syllid or citrus rust mites for an increase of about $2/acre in insecticide cost relative to chlorpyrifos. Average gross revenue is about $3,352 per acre for Florida oranges, implying impacts of about 0.6% of gross revenue per acre for the more conservative substitution scenario. Given an average of 95,000 acres treated with chlorpyrifos each year (Kynetec 2016; years 2010-2014), total impact is estimated to be between $190,000 and $3.1 million annually.

Table 2.4-17. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Florida Oranges.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Oranges (FL)	$13	Asian Citrus Psyllid	Zeta-cypermethrin [1]	$5	($8)
			Abamectin	$13	<$1
			Petroleum Oil	$15	$2
			Imidacloprid	$15	$2
			Fenpropathrin	$16	$3
		Citrus. Rust Mite/ Mites	Petroleum Oil [1]	$15	$2
			Abamectin [1]	$13	<$1
			Sulfur	$12	($1)
			Spirodiclofen	$26	$13
			Thiamethoxam	$15	$2

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

According to USDA reports, from 2010-2014, an average of 24,700 acres of citrus crops (all citrus) were grown in Texas and 16,300 acres of tangelos and tangerines were cultivated in Florida (USDA 2016a). Approximately 22% of the orange crop is treated with chlorpyrifos in both Florida and California; it seems reasonable that a similar percentage of citrus in Texas and similar crops would be treated with chlorpyrifos as well. Thus, EPA estimates that almost 9,000 acres of other citrus are currently treated annually with chlorpyrifos, on average. Assuming per-acre impacts are similar to the Florida orange scenario, total benefits for these other citrus crops in Florida and all citrus in Texas are estimated to range from $18,000 to $296,000 per year.

Peaches/Nectarines

Chlorpyrifos use on peaches and nectarines is limited to one application per year. For airblast applications, only a dormant or delayed dormant season spray can be made to the canopy. For post-bloom (growing season) applications, only trunk and lower scaffold limb applications are permitted, with spray not allowed to contact fruit. Such trunk applications target the peachtree borer and lesser peachtree borer, both of which have similar biology. One application of chlorpyrifos to the trunk and lower limbs at the rate of 3.0 lbs/100 gal (dilute application) typically provides good to excellent season-long control against borers (PSU, 2013). For these pests, the main alternative is likely to be hand-applied mating disruption dispensers.

Pre-bloom dormant or delayed dormant applications to peaches typically target San Jose scale or white peach scale. Similar to apples, pears, and plums, while petroleum oil is listed as an alternative with a high percentage of crop treated for San Jose scale, oil is often not an efficacious stand-alone tactic. IPM recommendations suggest applications of oil with an insecticide during the dormant/delayed dormant period to target susceptible stages. For San Jose scale, growers may attempt to control the ‘crawler’ stage (immature scales) later in the growing season using spirotetramat, pyriproxyfen, or pyrethroids (PSU, 2013). Alternatives for these pests can be substitutes for chlorpyrifos on a one for one basis. A single application of one of these alternative chemicals is expected to have efficacy similar to chlorpyrifos.

Because of differences in the share of acreage treated with chlorpyrifos, Georgia and South Carolina peaches are modeled separately from the rest of the country. Chlorpyrifos use on peaches is limited to one application per year. Therefore, as in apples discussed above, two alternatives scenarios are possible. For states other than Georgia and South Carolina, chlorpyrifos applications targeting scale pests ($13/acre) would be replaced by one application of a tank mix of petroleum oil ($22/acre) and esfenvalerate ($6/acre) to control scale pests for a combined cost of about $28/acre or $15/acre more than using chlorpyrifos. For applications to control borers, one application of chlorpyrifos would be replaced with the use of mating disruption ($40/acre), which would cost about $27 per acre more than chlorpyrifos (Table 2.4-18). At the lower bound, applications of phosmet may be feasible at a cost of $8/acre in additional chemical cost. With average gross revenue per acre of about $5,916 per acre for states other than Georgia and South Carolina, this represents 0.1 to 0.5% of gross revenue per acre. Given that about 13% of peach acreage is treated with chlorpyrifos outside of Georgia and South Carolina, EPA estimates 11,100 acres are treated with leading to a benefit estimate of $88,000 to $297,000 in total.

Table 2.4-18. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Peaches and Nectarines.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Peaches/ Nectarines, GA and SC	$8	Peachtree and lesser peachtree borer	No effective alternatives		
			Mating Disruption [1]	$40	$32
			Petroleum Oil [1]	$15	7
			Phosmet	$20	$12

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
		San Jose and white peach scale	Esfenvalerate [1]	$5	($3)
Peaches/ Nectarines, other states	$13	Lesser peachtree borer	Phosmet	$21	$8
			Esfenvalerate	$6	($7)
			Mating Disruption [1]	$40	$27
		San Jose and white peach scale	Petroleum Oil [1]	$22	$9
			Phosmet	$21	$8
			Esfenvalerate [1]	$6	($7)
			Pyriproxyfen	$42	$29
			Acetamiprid	$32	$19

Source: Kynetec 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
[1] Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

EPA received comments on the proposed tolerance revocation that discussed other pests of peach production in Georgia and South Carolina, specifically the lesser peachtree borer (Horton, 2016). EPA evaluated and verified the commenter's information about the pest and agreed with the conclusion that this pest is substantially more important in these states. Chlorpyrifos is used on a higher percentage of the peach acreage in Georgia and South Carolina, so these two states are considered separately. Information from state experts confirmed that alternatives were not effective, and usage data showed that only chlorpyrifos, not esfenvalerate or phosmet, was being used against this pest in this area. For acreage where lesser peachtree borer is uncontrolled, EPA assumes 10% yield loss for the purposes of cost estimation. Lesser peachtree borer reduces yield and shortens the life of the tree, but EPA has been unable to find reliable quantitative estimates for yield losses and shortened tree lifetime in peaches.

Based on information available for Michigan cherry (see the tart cherry section above), we model the yield loss at 10% for the affected acreage. The 10% loss estimate may be on the low end, as over time borers could colonize a larger percentage of the trees in an infested orchard. Gross revenue from peaches in Georgia and South Carolina averaged $4,178 from 2010 – 2014, so 10% yield loss would be about $418 per acre. An average of 17,900 acres were treated with chlorpyrifos in Georgia and South Carolina peaches for 2010 – 2014 (Kynetec, 2016). As a low-end estimate, we include treatments of petroleum oil ($15 per acre) and esfenvalerate ($5 per acre) to replace one treatment of chlorpyrifos at an increase $12 per acre for the control of scale pests. For the high-end estimate, we assume the same replacement at $12 per acre plus $418 per acre in lost revenue. For Georgia and South Carolina, the total benefit is from $215,100 to $7.8 million. This estimate is sensitive to the assumptions about yield loss and the share of treated acreage that will suffer those yield losses, and these are a source of substantial uncertainty. However, because most of the use of chlorpyrifos in these states seems to be targeting borer pests, the total benefit is likely to be in the higher end of this range.

Peanuts
Chlorpyrifos use in peanuts targets soil-dwelling insects: wireworms, rootworms, and borers (Kynetec 2016; years 2010-2014). The lesser cornstalk borer and the southern rootworms feed directly on the pegs and pods of the peanut plants (USDA, 2003b). Wireworms feed directly on

the roots of transplanted peanuts and the seeds (USDA, 2003b). Based on the available data, over the last five years, chlorpyrifos was the most used chemical to control borers and rootworms (Kynetec 2016; years 2010-2014). However, the insecticides used for wireworm control have been more variable. In 2009, aldicarb was the most used chemical to control wireworms, but no use of aldicarb is reported after 2010, because manufacturing ceased. While production of aldicarb has resumed recently, wireworms are not on the current label as target pests in peanut. Phorate was the major chemical used for wireworms in 2010, but use has declined since, perhaps because it can no longer be used at pegging. In 2011 and 2012, chlorpyrifos was the major insecticide for wireworms.

In peanuts, on average chlorpyrifos is applied once per season (Kynetec 2016; years 2010-2014). Table 2.4-19 shows the primary target pests for chlorpyrifos in peanuts, as well as potential alternatives and the difference in cost between the alternatives and chlorpyrifos. For the primary pests targeted by chlorpyrifos, EPA considers phorate and chlorantraniliprole as alternatives, based on market research data (Kynetec 2016; years 2010 – 2014). Of the two, phorate (an organophosphate) is less expensive. Chlorantraniliprole (a member of the relatively new diamide class of insecticides) only controls borers, while phorate controls all three, but is less effective against borers. Chlorpyrifos users would most likely replace one application of chlorpyrifos with one application of phorate to control the pests targeted with chlorpyrifos. The cost of phorate or chlorantraniliprole is lower than chlorpyrifos, but we are assuming that growers will use both chemicals to replace chlorpyrifos. The earlier EPA analysis (EPA 2015) modeled a treatment of diflubenzuron instead of chlorantraniliprole, but information received in public comments lead to revision of the analysis. Cost estimates for chlorantraniliprole are based on only one year of usage data.

Table 2.4-19. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Peanuts.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Peanuts	$21	Borers	Phorate	$14	($7)
			Chlorantraniliprole[1]	$17	($4)
		Rootworms	Phorate[1]	$14	($7)
		Wireworms	Phorate[1]	$14	($7)

Source: Kynetec 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

The alternatives scenario consists of replacing one application of chlorpyrifos ($21/acre) with an application of chlorantraniliprole ($17/acre) to control borers and an application of phorate ($14/acre) to control rootworms and wireworms. The total cost of the alternative regime is $10/acre more than the cost of chlorpyrifos. Gross revenue in peanut is $1,007 per acre, so the additional cost of chlorpyrifos alternatives is about 1% of gross revenue. EPA estimates that an average 114,000 acres of peanuts are treated from 2010 - 2014, implying total benefits of $1.1 million per year. However, as discussed above, using phorate in place of chlorpyrifos might result in yield loss if there is poor control of borers, leading to higher impacts.

Pears

Chlorpyrifos use on pears is limited to one application per year, made as a dormant/delayed dormant application. While applications against pear psylla are most common in terms of acres treated with chlorpyrifos (Kynetec 2016; years 2010-2014), chlorpyrifos plays a very small role relative to other active ingredients to control of this wide-spread pest. For San Jose scale, dormant/delayed dormant applications of chlorpyrifos with oil would target susceptible stages in the early season. While petroleum oil is listed as an alternative for San Jose scale, oil is often not an efficacious stand-alone tactic but is usually mixed with other insecticides, including chlorpyrifos (Murray and DeFrancesco 2014). When early season failures result, pear growers may attempt to control the crawler stage (immature scales) later in the growing season using spirotetramat, pyriproxyfen, buprofezin, and diazinon (Murray and DeFrancesco 2014).

Table 2.4-20 shows the primary target pest for chlorpyrifos in pears, San Jose and other scales, as well as potential alternatives and the difference in cost between the alternatives and chlorpyrifos. The alternative scenario for scale control consists of one application of a tank mix of petroleum oil ($14/acre) and pyriproxyfen ($40/acre). The baseline scenario of using chlorpyrifos is $17/acre and the cost of the alternative scenario is $54/acre. Therefore, the alternative scenario is about $37/acre more expensive than chlorpyrifos (difference may not be exact due to rounding). As chlorpyrifos may also be mixed with oil, the cost increase may only be the additional $23/acre incurred from switching to pyriproxyfen. Compared to chlorpyrifos alone, a combination of oil and lambda-cyhalothrin represents an increase in cost of $5/acre. Average gross revenue is about $8,060 per acre for pears (Appendix A), implying impacts of less than 0.5% of gross revenue per acre. EPA estimates that about 12% of pear acreage is treated with chlorpyrifos annually (Kynetec 2016; years 2010-2014) or about 6,000 acres. Thus, the benefits of chlorpyrifos is estimated to range from $30,000 to $223,000 per year.

Table 2.4-20. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Pears.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Pears	$17	San Jose Scale/Scale Complex	Petroleum Oil [1]	$14	($3)
			Pyriproxyfen [1]	$40	$23
			Lambda-cyhalothrin	$8	($9)
			Spirotetramat	$44	$27

Source: Kynetec 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
[1] Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

Pecans

Chlorpyrifos use in pecans primarily targets the pecan nut casebearer (Kynetec 2016; years 2010-2014). The casebearer is a major pest of pecan nuts throughout the pecan growing regions (USDA, 2002). One larva will consume all the nuts in a cluster (USDA, 2003c). Since 2009, growers have chosen chlorpyrifos over other chemicals, in terms of acres treated, followed by methoxyfenozide. Other pests for which chlorpyrifos has been selected include a complex of aphids (Kynetec 2016; years 2010-2014). Aphids can be a problem, especially the black pecan aphid, which possesses a toxin that induces leaf loss, usually impacting the crop the following year (USDA, 2001). Pecan phylloxera are also targeted with chlorpyrifos, particularly in Georgia (James 2015).

Chlorpyrifos is applied as a foliar treatment to control pecan nut casebearer. Most applications in the past three years have been at application rates of 0.75 to 1 pounds (lb) of active ingredient (ai) per acre. However, the range of application rates extends up to 3.75 to 4 lbs ai/acre. An average of 1.75 chlorpyrifos applications are made per acre (Kynetec, 2016, years 2010 – 2014).

Proper timing of any effective insecticide at the first-generation larvae of pecan nut casebearer will usually prevent subsequent applications (Knutson and Ree, 2015; Mulder and Grantham, undated). Methoxyfenozide, an insect growth regulator, is effective against pecan nut casebearer larvae. Imidacloprid is the primary insecticide used to control aphids in pecans (Kynetec, 2016; years 2010-2014). Chlorpyrifos may be part of a resistance management program for aphids (USDA, 2001). The most common alternative to chlorpyrifos is imidacloprid (Kynetec 2016; years 2010 -2014).

Table 2.4-20 shows the primary target pests for chlorpyrifos in pecan production, as well as the potential alternatives and the difference in cost between the alternatives and chlorpyrifos. The alternatives scenario consists of one application of chlorpyrifos ($8/acre) being replaced by one application of methoxyfenozide ($10/acre) to control pecan nut casebearer and one application of imidacloprid ($9/acre) to control aphids and pecan phylloxera. The total cost of the alternative scenario is $19/acre, about $11/acre more expensive than chlorpyrifos (difference may not be exact due to rounding). However, if only one pest is targeted, the increase in insecticide cost may be only $1 to $2 per acre. Average gross revenue is about $1,127 per acre (Appendix A), implying impacts of less than 1% of gross revenue per acre. Annually, an average of 115,000 pecan acres are treated with chlorpyrifos. Per-acre costs range from $1 to $11, implying total benefits of $115,000 to $1.3 million per year.

Table 2.4-20. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Pecans

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Alternatives ($/acre)	Difference in Cost ($/acre)
Pecans	$8	Pecan Nut Casebearer	Methoxyfenozide [1]	$10	$2
		Aphids and Pecan Phylloxera	Imidacloprid [1]	$9	$1

Source: Kynetec 2016; years 2010-2014, James (2015). Numbers may not add due to rounding.
Footnote:
[1] Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

Plums/Prunes

Chlorpyrifos use in plums and prunes is targeted for the control of San Jose scale. For San Jose scale, dormant/delayed dormant applications of chlorpyrifos with oil would target susceptible stages in the early season. While petroleum oil is listed as an alternative in Table 2.4-21, oil is often not an efficacious stand-alone tactic. For growers missing this early season control window, applications against crawlers later in the season would be made using a number of alternatives to chlorpyrifos.

Table 2.4-21. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Plums/Prunes

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Plums/ Prunes	$16	San Jose Scale/Scale Complex	Petroleum Oil [1]	$17	$1
			Esfenvalerate [1]	$6	($10)
			Pyriproxyfen	$45	$29
			Spirotetramat	$49	$33

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
[1] Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

Table 2.4-21 shows the potential alternatives and the difference in cost between the alternatives and chlorpyrifos. Alternatives can be substituted on a one-for-one basis with chlorpyrifos. Both chlorpyrifos and its alternatives could be tank-mixed with oil for a dormant application, and efficacy would be comparable (UC IPM, 2009b). EPA's lower bound alternative, however, assumes that chlorpyrifos ($16/acre) is applied alone and would be replaced by a tank mix of petroleum oil ($17/acre) and esfenvalerate ($6/acre). The baseline scenario of using chlorpyrifos is $16/acre and the cost of the alternative scenario is $23/acre. Therefore, the alternative scenario is about $7/acre more expensive than chlorpyrifos (difference may not be exact due to rounding). An upper bound of per-acre costs would be for growers to switch to spirotetramat, at an increase in insecticide cost of $33/acre. Average gross revenue is about $3,646 per acre for plums/prunes (Appendix A), implying impacts of 0.2% to 0.9% of gross revenue per acre. Chlorpyrifos use is relatively low in plums and prunes; approximately 2,900 acres are treated annually. Total benefits for chlorpyrifos is estimated to range from $20,000 to $96,000 per year.

Sorghum (milo)

The analysis for sorghum was updated more recently than other crops, using usage data from 2014-2018. Sugarcane aphids are the primary target of chlorpyrifos applications in sorghum (Kynetec 2019; years 2014-2018). This species recently became a major problem in sorghum (EPA, 2015b), particularly in southern grain sorghum production areas. Sugarcane aphids insert their piercing-sucking mouthparts into leaves to remove plant sap. Their excrement is in the form of sticky honeydew. Black sooty mold forms on the honeydew, which potentially reduces photosynthetic efficiency. Severe sugarcane aphid infestations prior to flowering or during grain development can reduce yield (Bowling et al, 2016). Harvesting efficiency can also be affected because sticky honeydew that settles on foliage and grain heads causes material to build up in the separator of a combine (see reference in Bowling et al, 2016).

Chlorpyrifos is used early in the season due to a relatively long pre-harvest interval. During 2016, two new products were first registered in sorghum that contained the active ingredients sulfoxaflor and flupyradifurone (Sorghum Checkoff 2016). If these are used in place of chlorpyrifos, there is an additional cost of $3-4 per acre (Table 2.3.22).

Table 2.4-22. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Sorghum

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Sorghum	$4	Sugarcane Aphid/Other Aphids	Sulfoxaflor[1]	$7	$3
			Flupyradifurone	$11	$7

Source: Kynetec, 2016; years 2014-2018. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

Table 2.4-22 above shows the potential alternatives and the difference in cost between the alternatives and chlorpyrifos. Alternatives can be substituted on a one-for-one basis with chlorpyrifos. The cost of the baseline scenario using chlorpyrifos is $4/acre and the cost of the alternative scenario is $7/acre. Therefore, the alternative scenario is about $3/acre more expensive than chlorpyrifos (difference may not be exact due to rounding). An upper bound of per-acre costs would be for growers to switch to flupyradifurone, at an increase in insecticide cost of $7acre. Average gross revenue is about $245 per acre for grain sorghum (Appendix A), implying impacts of 1.2% to 2.9% of gross revenue per acre. Chlorpyrifos use averages about 108,000 acres are treated annually. Total benefits for chlorpyrifos is estimated to range from $324,000 to $756,000 per year.

Soybeans

Chlorpyrifos labels allow for multiple applications per year in this crop, including pre-plant soil and post-emergence foliar applications. On average, however, chlorpyrifos is applied once per year to soybeans; only about three percent of acres are treated twice (Kynetec 2016; years 2010-2014). Nationally, the average application rate is 0.36 lb ai/acre. The major pests targeted by chlorpyrifos in soybean production are shown in Table 2.4-23.

Soybean aphid is the leading target pest for chlorpyrifos applications to soybeans, by acres treated (Kynetec 2016; years 2010-2014). This invasive insect from Asia is a sap feeding pest that occurs sporadically over much of the United States, requiring applications of one or more foliar insecticides. Likely alternatives for this pest would be foliar applications of lambda-cyhalothrin, thiamethoxam, or imidacloprid. Thiamethoxam and imidacloprid have systemic activity, while lambda-cyhalothrin has broad-spectrum knockdown activity. Spider mites and bean leaf beetles are also targeted by applications of chlorpyrifos, with similar efficacy observed among the same alternatives listed for soybean aphid: lambda-cyhalothrin, thiamethoxam, and imidacloprid (Kynetec 2016; years 2010-2014). The most likely substitution scenarios for soybean growers in the absence of chlorpyrifos would be to apply any of these available alternatives, with substitution on a one-for-one basis with chlorpyrifos.

Table 2.4-23. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Soybeans

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternative	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Soybeans	$3	Soybean Aphid	Lambda-cyhalothrin	$4	$1
			Thiamethoxam [1]	$7	$4
			Imidacloprid	$8	$5
		Bean Leaf Beetle	Lambda-cyhalothrin	$4	$1
			Thiamethoxam [1]	$7	$4
			Imidacloprid	$8	$5
		Spider Mite	Lambda-cyhalothrin	$4	$1
			Thiamethoxam [1]	$7	$4
			Imidacloprid	$8	$5

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
[1] Chemical used to estimate the cost of control in the absence of chlorpyrifos. One application of thiamethoxam is expected to control either or both the soybean aphid and the bean leaf beetle.

EPA's alternatives scenario consists of one application of chlorpyrifos ($3/acre) per season being replaced by one application of thiamethoxam ($7/acre) to control soybean aphid and bean leaf beetle. The baseline scenario of using chlorpyrifos is $3/acre and the cost of the alternative scenario is $7/acre. Therefore, the alternative scenario is about $4/acre more expensive than chlorpyrifos (difference may not be exact due to rounding). However, costs could be as low as $1/acre with the use of lambda-cyhalothrin. Average gross revenue is about $526 per acre, implying impacts of about 0.2% to 0.8% of gross revenue per acre. EPA estimates that almost 3.1 million acres of soybean are treated annually with chlorpyrifos, so the total benefit ranges from $3.1 million to $12.2 million.

Strawberries

Chlorpyrifos use in strawberries targets a complex of lepidopteran larvae, including cutworms and various armyworms (Kynetec 2016; years 2010-2014). Early in the season, these pests will eat foliage and even the crown of young plants. Later in the season, these larvae feed directly on the berries (Mossler, 2012; UC IPM, 2014c). Chlorpyrifos is used early in the season, as there is a 21-day pre-harvest interval.

EPA received comments on pests specific to strawberry production in Oregon, specifically the soil pest, garden symphylan (Unger, 2016). Earlier usage data confirm that symphylans are the main pest targeted with chlorpyrifos in Oregon (Kynetec 2016; years 2010-2014), although usage data are no longer collected for Oregon strawberries. Furthermore, it appears that chlorpyrifos is the only pesticide used to control garden symphylans in this crop. Extension descriptions confirm that symphylans can sometimes be significant pests of newly planted strawberries and other crops in western Oregon (Jesse and Dreves 2020).

For the lepidopteran larvae, methoxyfenozide (an insect growth regulator) is the most likely alternative to chlorpyrifos but would not have any impact on other pests that might be present, such as the strawberry bud weevil. *Bacillus thuringiensis* (*Bt*) is a biopesticide with a very short pre-harvest interval (PHI). It is used multiple times during the harvest season, especially in organic production, but also in conventional strawberry production. Therefore, *Bt* may be applied to strawberries that have had chlorpyrifos applied earlier in the season. *Bt* is effective on only young lepidopteran larvae. As a conservative estimate, without chlorpyrifos, there may be three to five additional applications of *Bt*. There may be other pesticides needed for control of pests other than lepidopterans.

Table 2.4-24 shows the primary target pest for chlorpyrifos in strawberry as well as potential alternatives and the difference in cost between the alternatives and chlorpyrifos. For the primary pests targeted by chlorpyrifos, *Bt* and methoxyfenozide are the alternatives, as both control a variety of lepidopteran larvae. The reported cost for *Bt* represents five applications because multiple *Bt* applications that would be needed to replace one application of chlorpyrifos in strawberry. A single application of methoxyfenozide could replace one application of chlorpyrifos in strawberry to control lepidopteran larvae.

Table 2.4-24. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Strawberry.

Crop	Cost of Chlorpyrifos ($/Acre)	Target Pest	Alternatives to Chlorpyrifos	Cost of Alternatives	Difference in Cost ($/acre)
Strawberry, Other than Oregon	$10	Lepidopteran Larvae ("Worms")	*Bt* [1]	$75 ($15.50 up to 5x)	$65
			Methoxyfenozide [1]	$20	$10
			Spinetoram	$48	$38
			Chlorantraniliprole	$27	$17
Strawberry, Oregon	$12	Garden Symphylan	No Effective Alternatives		
		Weevil Complex	Carbaryl	$18	$6

Source: Kynetec 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos. *Bt* cost reflects multiple applications to achieve similar control.

The alternatives scenario consists of either five applications of *Bt* or one application of methoxyfenozide (states other than Oregon). The cost for one application of chlorpyrifos is $10 per acre. The cost for five applications of *Bt* to replace one application of chlorpyrifos is approximately $75 per acre while a single methoxyfenozide application is about $20 per acre. Therefore, the estimated alternative scenarios cost about $10 to $65 per acre more than chlorpyrifos. Average gross revenue is about $42,821 per acre (Appendix A), implying impacts of less than 0.1% of gross revenue per acre. On average, about 10,500 acres of strawberry are treated with chlorpyrifos outside Oregon. Total benefits for strawberry would cost growers in areas outside Oregon between $105,000 and $686,000 per year.

In Oregon, growers using chlorpyrifos to target multiple species of weevils might use carbaryl as an alternative. The average cost for chlorpyrifos is $12/acre while carbaryl averages $18/acre, an increase of $6/acre in chemical cost. Strawberry crown moth is another pest for which chlorpyrifos is recommended, but usage data show more use of carbaryl against this pest in Oregon (Kynetec 2016; years 2010 – 2014). Nearly all chlorpyrifos use, however, targets symphylans, for which there are no effective alternatives. Because there are no effective alternatives (Unger, 2016), yield loss estimates are 100% in the fields infested with symphylans without effective control. USDA yield and price data were used to calculate gross revenue per acre of $7,813 per acre in Oregon strawberry (USDA, 2016c). The affected acreage that is treated with chlorpyrifos averages 600 acres, annually, but 545 acres of chlorpyrifos acres are targeting symphylans annually (Kynetec 2016; years 2010 - 2014). The total incremental cost estimate for Oregon strawberry ranges from a low of $3,600, which assumes all acres are only targeting weevils, to about $4.3 million. Given the high proportion of acreage treated for garden symphylan, the cost is likely near the upper bound. This cost to Oregon growers is in addition to the cost estimated in the previous paragraph to growers outside of Oregon accounts for all affected strawberry acreage nationally. The total benefit in strawberry is estimated to be $109,000 to $5.0 million annually.

Sugarbeets

The analysis for sugarbeets was updated more recently than other crops, using usage data from 2014-2018. Nationally, chlorpyrifos use in sugarbeets primarily targets sugarbeet root maggot and leafminers (Kynetec 2016; years 2014-2018). Applications targeting root maggots are likely to be made at planting, while applications targeting leafminers would be foliar sprays or post crop emergence. Published extension recommendations (Hollingsworth 2019) indicate that there are several foliar insecticides that can control leafminer outbreaks, such as zeta-cypermethrin, azadirachtin, clothianidin, thiamethoxam, and spinosad, so substitution for alternatives with chlorpyrifos would be one-for-one to control that pest. For maggots, neonicotinoid seed treatments are registered, used widely, and known to be effective. For a seed treatment scenario, there would also be a potentially saving in the cost of applying chlorpyrifos (*i.e.*, no equipment and fuel costs for a separate at-planting application). For the other alternatives applied to soil, substitution would be one-for-one with chlorpyrifos.

Particularly important problems with sugarbeet root maggot were identified by industry experts in a few counties in the Minnesota counties of Clay, Kittson, Marshall, Norman, Polk and Wilkin, and the North Dakota counties of Grand Fork, Pembina, Traill and Walsh (Kahn, 2016). Experts estimate that without adequate control, infestation of sugarbeet root maggot in these areas can lead to yield losses of 45% (Boetel, 2016).

Outside Minnesota and North Dakota, an alternative scenario in the absence of chlorpyrifos consists of one application of a clothianidin seed treatment ($22/acre) at-planting to control sugarbeet root maggot and one foliar application of zeta-cypermethrin ($4/acre) to control leafminers, replacing two applications of chlorpyrifos ($6/acre each) (Table 2.4-25). The baseline scenario of using chlorpyrifos is $12/acre and the cost of the alternative scenario is $26/acre. Therefore, the alternative scenario is about $14/acre more expensive than chlorpyrifos. Per-acre cost would be similar for a single pest, with a clothianidin seed treatment costing $10 more than a single treatment of chlorpyrifos (Table 2.4-25). Average gross revenue from 2014 - 2018 outside of Minnesota and North Dakota is about $1,440 per acre (Appendix A), implying impacts of 0.9% of gross revenue per acre. On average, 140,000 acres are treated with chlorpyrifos in states other than Minnesota and North Dakota, implying total benefits of $1.8 million per year.

Table 2.4-25. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Sugarbeets.

Crop	Cost of Chlorpyrifos ($/Acre)	Target Pest	Alternatives to Chlorpyrifos	Cost of Alternatives	Difference in Cost ($/acre)
Sugarbeets, other states	$6	Leafminer	Zeta-cypermethrin [1]	$4	($2)
			Cyfluthrin (ST)	$4	($2)
			Clothianidin (ST)	$22	$16
		Sugarbeet Root Maggot	Clothianidin (ST) [1]	$22	$16
			Cyfluthrin (ST)	$4	($2)
			Terbufos	$17	$11
			Zeta-cypermethrin	$3	($3)
Sugarbeets, MN	$6	Cutworm	Clothianidin (ST)	$22	$16
			Cyfluthrin (ST)	$4	($2)
			Terbufos[1]	$17	$11
			Zeta-cypermethrin	$4	($2)
		Sugarbeet Root Maggot	Clothianidin (ST)	$22	$16
			Cyfluthrin (ST)	$4	($2)
			Terbufos	$17	$11
			Zeta-cypermethrin	$3	($3)
			No effective alternatives in heavily infested areas[1]	45% yield loss	
Sugarbeets, ND	$6	Sugarbeet Root Maggot	Clothianidin (ST)	$22	$16
			Cyfluthrin (ST)	$4	($2)
			Terbufos	$17	$11
			Zeta-cypermethrin	$3	($3)
			No effective alternatives in heavily infested areas[1]	45% yield loss	

Source: Kynetec 2016; years 2014-2018. Numbers may not add due to rounding. ST denotes a seed treatment. Kynetec no longer tracks the cost of seed treatments, so the seed treatment cost data are based on use from 2010 – 2014.
Footnote:
[1] Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

In Minnesota and North Dakota, sugarbeet root maggot is the primary pest, and cutworm appears to be a target of chloropyrifos in MN. Alternatives to chlorpyrifos for maggot and cutworm control would be clothianidin seed treatments, costing $16 per acre more than chlorpyrifos, or a soil application of terbufos, costing about $11 acre more than chlorpyrifos (Table 2.4-25). To target adults of the root maggots, growers in heavily affected counties might use a foliar application of a pyrethroid, but instead we model yield losses of 45% from poor control, based on Boetel (2016). Gross revenues are calculated from USDA yield and revenue data, and average about $1,100 per acre in both states from 2014-2018 (USDA 2020), so yield losses are estimated at $498 per acre in North Dakota and Minnesota. The total estimated incremental costs from chlorpyrifos tolerances, given an average of 61,200 affected acres in Minnesota and North Dakota, is $900,000 to $30.5 million per year. However, acres in the counties identified as severely affected by root maggot account for less than 20% of chlorpyrifos-treated acres in Minnesota and about 10% of chlorpyrifos-treated acres in North Dakota (Kynetec 2016; years 2014-2018), so total annual costs are likely to be about $5.1 million annually. These costs are in addition to the costs in other states estimated in the previous paragraph. The total benefit of chlorpyrifos for all sugarbeet is estimated to be $2.6 to $32.2 million per year. However, the benefit is likely closer to $6.8 million when considering the limited extent of severe sugarbeet root maggot problems that would remain uncontrolled without chlorpyrifos.

Sunflowers

Chlorpyrifos use in sunflower targets a mix of lepidopteran larvae, or caterpillars (Kynetec 2016; years 2010-2014). There are several moth pests in the sunflower growing regions. Cutworms live in the soil and reduce the establishment of the stand (USDA, 1999b). Chlorpyrifos has been used as a soil treatment at plant for these soil pests, but in more recent years, neonicotinoid seed treatments are more likely to be used to control cutworms. Other moths that feed on foliage or sunflower heads are treated with foliar applications.

Table 2.4-26 shows the primary target pest for chlorpyrifos in sunflower as well as the potential alternatives and the difference in cost between the alternatives and chlorpyrifos. For the primary foliar pests targeted by chlorpyrifos, lambda-cyhalothrin and esfenvalerate, among other synthetic pyrethroids, are the alternatives used to control lepidopteran larvae. Costs are essentially the same but the synthetic pyrethroids are used more than chlorpyrifos in terms of acres treated.

Table 2.4-26. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Sunflower.

Crop	Cost of Chlorpyrifos ($/Acre)	Target Pest	Alternatives to Chlorpyrifos	Cost of Alternatives	Difference in Cost ($/acre)
Sunflower	$4	Lepidopteran Larvae	Lambda-cyhalothrin	$4	<$1
			Esfenvalerate [1]	$4	<$1

Source: Kynetec, 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

The alternatives scenario consists of one application of chlorpyrifos ($4/acre) being replaced with one application of esfenvalerate ($4/acre) to control lepidopteran larvae. The alternatives scenario costs approximately the same as, or about $1/acre more than, chlorpyrifos. Average gross revenue is about $352 per acre (Appendix A), implying impacts of less than 0.1% of gross revenue per acre. EPA estimates that about 123,000 acres of sunflower are treated annually with chlorpyrifos, which signifies a total benefit nationally of less than $123,000 per year.

Sweet Corn

Chlorpyrifos is used to control several sweet corn pests, primarily soil pests that include corn rootworms, seedcorn maggot, garden symphylan, and wireworms but also foliar pests such as cutworms and armyworms (Kynetec 2016; years 2010-2014). Most chlorpyrifos usage targets soil pests with pre-plant or at-planting applications to soil. Some small amount of usage are foliar applications, which could also control adult rootworms (beetles) during the growing season. About 10% of the treated area is treated more than once (Kynetec 2016; years 2010-2014).

Chlorpyrifos is also registered as a seed treatment use on sweet corn. Because seed treatment usage data were not available for sweet corn, the percent of the crop treated is underestimated and thus the benefits of chlorpyrifos may also be underestimated.

Garden symphylan is mainly a regional concern in the Pacific Northwest, particularly Oregon. While this pest accounts for a small amount of chlorpyrifos usage nationally, the data suggest that this is a significant pest targeted by chlorpyrifos applications in Oregon, again via soil applications at planting.

Substitution with other at-plant soil-applied materials would be one-for-one with chlorpyrifos. Besides other broad-spectrum insecticide applications, seed treatments with neonicotinoid insecticides provide control of the soil pest complex, though control of rootworm is highly rate-dependent. Usage of neonicotinoid seed treatments could potentially save the additional cost of an at-plant application. However, if growers are making soil applications, it is likely that they would substitute a soil application of bifenthrin, tefluthrin (except in California), or terbufos for chlorpyrifos (Table 2.4-27). For foliar pests, replacement of chlorpyrifos with a foliar alternative like methomyl or a synthetic pyrethroid would be likely. Neonicotinoid seed treatments are available as a possible replacement for chlorpyrifos-treated seed for sweet corn, but EPA does not have data on their use or any cost differences as compared to chlorpyrifos treatments.

Table 2.4-27. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Sweet Corn.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Sweet Corn	$15 (soil application)	Rootworm	Bifenthrin	$12	($3)
			Lambda-cyhalothrin	$5	($7)
			Tefluthrin [1]	$16	$1
		Seed Maggot/ Wireworm	Bifenthrin	$12	($3)
			Phorate	$15	<$1
			Tefluthrin [1]	$16	$1
		Garden Symphylan	Bifenthrin	$12	($3)
			Terbufos	$17	$2
			Chlorethoxyfos	$15	(<$1)
			Tefluthrin [1]	$16	$1
	$8 (foliar application)	Armyworm/ Cutworm	Methomyl [1]	$10	$2
			Lambda-cyhalothrin	$5	($3)
			Zeta-cypermethrin	$5	($3)

Source: Kynetec 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos. One application of tefluthrin is expected to control all soil pests. However, this insecticide is not registered in California.

EPA's projected alternatives scenario consists of replacing one soil application of chlorpyrifos ($15/acre) with one application of tefluthrin ($16/acre) to control corn rootworms, garden symphylan, seedcorn maggot, and wireworms. Replacing one foliar application of chlorpyrifos ($8) would entail one foliar application of methomyl ($10/acre) to control cutworms and/or armyworms. In total, the chlorpyrifos regime would cost $23/acre per year while the alternative strategy of tefluthrin and methomyl would cost about $26/acre per year. This implies an increase in pest control costs of about $3/acre per year. For any single application, increases in cost may range from $1 to $2/acre. Gross revenue in sweet corn, considering both fresh and processing, averages $1,890/acre. The increase in cost represents about 0.2% of gross revenue. An average of 54,300 acres of sweet corn are treated with chlorpyrifos each year. Total benefits are estimated to range from $54,000 to $163,000 annually. Tefluthrin is not registered in California, so growers there would need to use another alternative. As the other alternatives are less expensive, the national estimates are overestimates for California. There may be somewhat different impacts for growers replacing seed treatments, but they are unlikely to be significant. In field corn, neonicotinoid seed treatments are less expensive and much more widely used that chlorpyrifos, so they may be a viable alternative in sweet corn.

Tobacco

Chlorpyrifos use in tobacco is to control cutworm caterpillars and wireworms (beetle larvae), both soil insect pests (Kynetec, 2016; years 2010-2014). These insect pests occur more often when tobacco follows sod, tobacco, or corn (USDA, 2008). These insects are considered minor or occasional pests in most tobacco growing regions (USDA, 1999c). In past years, chlorpyrifos and acephate have been used as a soil treatment prior to transplant to control these pests. More recently, fumigations and ethoprop, applied for nematode control, also controls wireworms (USDA, 1999c; USDA, 2008). Newer chemicals, such as imidacloprid, that target major lepidopteran (caterpillar) pests will also control cutworms.

Currently one application of chlorpyrifos ($11/acre) is used to control cutworms and wireworms in tobacco. The alternatives scenario consists of replacing one application of chlorpyrifos with one application of imidacloprid ($15/acre) to control cutworms and/or wireworms. The scenario is about $4/acre more expensive than chlorpyrifos. Gross revenue averages $4,247 per acre (Appendix A), implying impacts of less than 0.1% of gross revenue. On average, about 37,300 acres of tobacco are treated annually with chlorpyrifos. The total benefit of chlorpyrifos tolerance is estimated to be $149,000 per year.

Table 2.4-28. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Tobacco.

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternative	Cost of Alternative ($/acre)	Difference in Cost ($/acre)
Tobacco	$11	Cutworms and Wireworms	Acephate	$7	($4)
			Imidacloprid [1]	$15	$4

Source: Kynetec 2016; years 2010-2014. Numbers may not add due to rounding.
Footnote:
[1] Chemicals used to estimate the cost of control in the absence of chlorpyrifos.

Walnuts

Chlorpyrifos use on walnuts is limited to two applications per year, including dormant/delayed dormant sprays and in-season foliar sprays. On average, about half the acreage treated with chlorpyrifos is treated once per year, and the other half is treated twice per year Chlorpyrifos is applied once on about half of the treated acreage, while the other half is treated twice per year (Kynetec 2016; years 2010-2014). Most chlorpyrifos usage, in terms of acres treated, is for walnut husk fly and/or codling moth. There are numerous effective alternatives available for both pests (Kynetec 2016; years 2010-2014). For walnut husk fly, a bait-based attract-and-kill strategy is recommended with a number of effective insecticide components mixed with a fly attractant (UC IPM, 2013a). For codling moth, early and mid-season foliar chlorpyrifos applications are made to target egg hatch, but several alternatives are available for effective control of this pest (UC IPM, 2013b). For navel orangeworm, another chlorpyrifos-target pest, cultural control tactics are recommended as a primary management strategy in walnuts, with insecticidal treatments mostly considered for applications targeting the third flight of adult moths (UC IPM, 2011a).

Table 2.4-29 shows the primary target pests for chlorpyrifos in walnuts as well as potential alternatives and the difference in cost between the two. EPA projects that one application of bifenthrin with bait ($16/acre) would replace one application of chlorpyrifos with bait ($19/acre) for control of walnut husk fly. A second application of bifenthrin would also replace one separate application of chlorpyrifos for control of codling moth at some point in the season. Since bifenthrin is less expensive than chlorpyrifos, no impact is projected, but EPA cannot explain why growers do not already follow this program. Given that usage data (Kynetec, 2016 years 2010 – 2014) indicates an overall preference by growers for chlorpyrifos over similarly priced or even less expensive pyrethroid and neonicotinoid alternatives, uncertainty remains as to whether efficacy or other IPM considerations may drive other potential benefits of chlorpyrifos usage on walnuts. More reasonable alternatives for walnut husk fly might be malathion ($2/acre more than chlorpyrifos – lower bound impact) or acetamiprid or spinosad at $18/acre more than chlorpyrifos. Methoxyfenozide ($6/acre more than chlorpyrifos) or chlorantraniliprole ($18/acre more than chlorpyrifos) could replace chlorpyrifos for control of codling moth or navel orangeworm. At the upper bound, one application each of acetamiprid and chlorantraniliprole could replace two chlorpyrifos applications for $36/acre increase in insecticide cost. Average gross revenue is about $5,591 per acre (Appendix A). EPA estimates that 124,000 acres of walnut are treated annually; the total benefit of chlorpyrifos for walnuts is estimated to range from $248,000 to $4.5 million per year.

Table 2.4-29. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Walnuts

Crop	Cost of Chlorpyrifos ($/acre)	Target Pest	Alternatives	Cost of Alternatives ($/acre)	Difference in Cost ($/acre)
Walnuts	$19	Walnut Husk Fly	Bifenthrin	$16	($3)
			Acetamiprid	$37	$18
			Esfenvalerate	$9	($11)
			Spinosyn	$37	$18
			Imidacloprid	$8	($11)
			Malathion[1]	$21	$2
			Spinetoram	$38	$19
		Codling Moth	Bifenthrin [1]	$16	($3)
			Chlorantraniliprole	$37	$18
			Esfenvalerate	$8	($11)
			Lambda-cyhalothrin	$6	($13)
			Acetamiprid	$37	$18
			Methoxyfenozide	$25	$6
			Imidacloprid	$8	($11)
			Spinetoram	$38	$19
		Navel Orangeworm	Chlorantraniliprole	$37	$18
			Bifenthrin	$16	($3)
			Permethrin	$6	($13)

Source: Kynetec 2016; years 2010-2014. Numbers may not add due to rounding. *Footnote*:

1 Chemicals used to estimate the cost of control in the absence of chlorpyrifos. Two applications of chlorpyrifos are permitted and bifenthrin could be used for either.

Other Crops

Chlorpyrifos is also registered on sites for which use is relatively small in terms of acres treated compared to acres grown. A low proportion of treated acres frequently indicates that cost-effective alternatives are available and/or that targeted pests are not particularly damaging. Table 2.4-30 presents information on the pests targeted by chlorpyrifos and some potential alternatives in order to estimate benefits for chlorpyrifos on these crops.

Table 2.4-30. Chlorpyrifos Target Pests, Alternatives, and Chemical Costs, Various Sites

Crop	Target Pest	Control method	Cost ($/acre)	Difference in Cost Between Control Method and Chlorpyrifos ($/acre)
Apricot	Borers	Chlorpyrifos	$7	
		Esfenvalerate	$5	($2)
		Methoxyfenozide	$21	$14
Beans, succulent	Symphylans, Maggots	Chlorpyrifos	$9	
		Ethoprop	$38	$29
		Bifenthrin	$3	($6)
Beans, dry	Red Spider Mite, Wireworms	Chlorpyrifos	$5	
		Malathion	$5	($<1)
		Zeta-cypermethrin	$2	($3)
		Ethoprop	$24	$19
Corn, field	Corn Rootworm	Chlorpyrifos	$9	
		Tefluthrin	$17	$8
		Tebupirimphos*	$15	$6
		Bifenthrin	$7	($2)
Peas, succulent	Maggots	Chlorpyrifos	$10	
		Esfenvalerate	$5	($5)
		Bifenthrin	$3	($7)
		Neonicotinoid Seed Treatment	$20-$75	$10-$65
Peppers	Aphids and Thrips	Chlorpyrifos	$8	
		Imidacloprid	$18	$10
		Spinetoram	$38	$30
Tomato	Caterpillars	Chlorpyrifos	$10	
		Methoxyfenozide	$17	$7
Wheat, Spring	Aphids	Chlorpyrifos	$3	
		Lambda-Cyhalothrin	$3	<$1
		Cyfluthrin	$3	(<$1)
		Thiamethoxam	$4	$1
		Imidacloprid	$2	($1)
Wheat, Winter	Aphids and Mites	Chlorpyrifos	$4	
		Imidacloprid	$4	(<$1)
		Thiamethoxam	$4	<$1

Source: Kynetec 2016; years 2010-2014. Numbers may not add due to rounding.
*Another common name for this active ingredient is phostebupirim; not available in California.

The benefits of chlorpyrifos in apricot are probably similar to other stone fruit, especially plums and prunes since most commercial production is in California. Insecticide costs in plums and prunes are expected to range between $7 and $33/acre more than with use of chlorpyrifos (Table

2.4-23). Borers are the primary chlorpyrifos target in apricot, but it is not a primary method of control (Kynetec 2016; years 2010-2014). Synthetic pyrethroids, such as esfenvalerate, tend to be less expensive than chlorpyrifos; methoxyfenozide is about $14/acre more expensive. EPA estimates that about 100 acres of apricot are treated each year, implying total benefits of $1,000 to $3,000 annually, using the range in cost estimated for plums and prunes.

Soil-dwelling pests are targeted by chlorpyrifos in green and other succulent beans (Kynetec 2016; years 2010-2014). Some of these pests, for example symphylans, are reported to be particularly problematic in other vegetables or in crops like strawberry. Symphylans appear to be a rare problem in beans, however; less than two percent of the crop is treated with chlorpyrifos. Alternatives may be expensive; ethoprop costs $29/acre more than a chlorpyrifos treatment. On average, about 4,700 acres of beans are treated annually, implying total benefits of chlorpyrifos in beans of $137,000 per year.

In dry beans, chlorpyrifos targets red spider mite and wireworms (Kynetec 2016; years 2010 – 2014). For both pests, there are multiple alternatives in use that are similar in cost to chlorpyrifos, although growers also use ethoprop to target wireworms at a cost of $19 per acre more than chlorpyrifos. On average, about 6,200 acres of dry beans are treated with chlorpyrifos annually, implying the total benefits of $0 to $118,000 annually.

Chlorpyrifos is mainly used for corn rootworm control in field corn (Kynetec 2016; years 2010-2014). Most of the acres treated with chlorpyrifos are treated at planting, but some are treated later in the season. Rootworm is mainly controlled at planting with plant incorporated protectants (PIPs) or seed treatments, including seed treated with chlorpyrifos. Chlorpyrifos may be used with PIPs, but it is often applied to conventional corn or herbicide-tolerant corn without traits for rootworm control. Due to restrictions on acreage planted to PIPs for resistance management purposes, they are unlikely to provide an alternative for chlorpyrifos. Neonicotinoid seed treatments may provide an option, but they tend to be less expensive, which implies chlorpyrifos is used in situations where neonicotinoids are inappropriate. As shown in Table 2.4-30, tefluthrin and tebupirimphos, as a soil application, are the most likely alternatives and cost $6 to $8 per acre more than chlorpyrifos. Either could also be used to replace a chlorpyrifos application later in the season. On average, 677,000 acres per year of corn are treated with chlorpyrifos. The total benefits for corn is estimated to be $4.1 to $5.4 million annually.

For green peas, the main target pests of chlorpyrifos use are seed maggots (Kynetec 2016; years 2010-2014). Alternative insecticides used in peas for control of seed maggots are synthetic pyrethroids, which are generally cheaper than chlorpyrifos. EPA assumes that chlorpyrifos is chosen in situations when pyrethroids would not provide adequate control. As with onion (Table 2.4-15), neonicotinoid-treated seeds may be a feasible option, implying an increase in control cost of $10 to $65 per acre. This assumes onion seed treatments are a reasonable approximation of seed cost. Maggots may be particularly damaging at crop germination, similar to *Brassica* crops, and control failure could lead to substantial losses. If yield loss is similar to the situation in *Brassica*, i.e., about 48%, impacts could be as high as $370 per acre. Less than 500 acres of green peas are treated annually, so total benefit to producers of green peas might range from $4,000 to $166,000 per year.

Chlorpyrifos is primarily used to control aphids and thrips in peppers (Kynetec 2016; years 2010-2014). As shown in Table 2.4-30, alternatives such as imidacloprid and spinetoram cost, on average, $10 to $30 per acre more than does chlorpyrifos. Given an average of about 500 acres of peppers treated each year with chlorpyrifos, estimates of the total benefit to pepper producers range from $5,000 to $15,000 per year.

Very little chlorpyrifos is used in tomato production; caterpillars, such as armyworms and cutworms, appear to be the primary target pests. There are numerous alternatives registered, with methoxyfenozide the most commonly used chemical control. As shown in Table 2.4-30, use of methoxyfenozide instead of chlorpyrifos may increase costs to the grower by about $7/acre. As only about 1,600 acres of tomato are treated with chlorpyrifos per year, on average, the benefits of chlorpyrifos is about $11,000 annually.

Chlorpyrifos is largely used for aphid control in spring and winter wheat (Kynetec 2016; years 2010-2014). There are several alternatives, particularly neonicotinoid insecticides like imidacloprid and thiamethoxam, that are similar in cost. Per acre, any increase in cost is likely to be under $1/acre. About 783,000 acres of spring wheat and 549,000 acres of winter wheat are treated annually with chlorpyrifos. Total benefit, therefore, ranges from $0 to $783,000 for spring wheat and up to $549,000 for winter wheat.

There are three sites for which chlorpyrifos is registered, figs, kiwifruit, and pistachio, that are primarily grown in California. California pesticide use reports show that less than 10 fields, covering just over 100 acres of these three crops, were treated with chlorpyrifos in the five years between 2010 and 2014. Similarly, market research data (Kynetec 2016; years 2010 – 2014) show negligible use of chlorpyrifos on celery and garlic (also primarily grown in California) from 2010 to 2014. Given the lack of consistent chlorpyrifos usage, EPA concludes that there is likely no significant benefit to growers of these crops.

Finally, chlorpyrifos is registered as a seed treatment for several vegetable crops, most notably cantaloupe, watermelon, cucumber, pumpkin, and squash. EPA does not have data as to the extent that chlorpyrifos-treated seeds are used and received no public comments regarding usage. In place of chlorpyrifos-treated seeds, growers could use seeds treated with other insecticides or make soil applications at planting. According to Kynetec (2016) years 2010-2014), there are numerous pesticides used for these vegetables at planting, ranging in cost from $3 to $36/acre. The most commonly used insecticide, imidacloprid, costs about $18/acre (Kynetec 2016). These costs would overstate the incremental cost of the chemical replacing chlorpyrifos, since it does not account for the cost of the seed treatment. There may be some increase in application costs if growers switched from seed treatment to a soil application, but since the application would accompany the planting operation, additional labor and machinery costs may be small. EPA has no information regarding the acreage that might be affected.

In addition to these crops, EPA did not estimate costs of control for livestock uses of chlorpyrifos. Most livestock-related active registrations of chlorpyrifos are for treatment of housing and processing premises. The only direct use of chlorpyrifos in U.S. livestock production is for a cattle ear tag to repel and kill flies. The benefits of chlorpyrifos for this use are discussed qualitatively in a separate assessment by BEAD (US EPA, 2020c).

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Appendix A. Grower Revenue

EPA utilized data on area cultivated and value of production from the National Agricultural Statistics Service (NASS) of USDA to calculate average gross revenue per acre. A five-year (2010 – 2014) average is used unless recent price increases indicate substantially higher revenues currently.

Crop	Acres Harvested (Avg. Annual)	Gross Revenue (Avg. Annual)	Gross Revenue (Avg. Annual $ per acre)
ALFALFA (hay)	18,375,000	$10,038,403,600	$546
ALMONDS	822,000	$5,100,158,000	$6,205
APPLES	326,730	$2,892,088,600	$8,852
APRICOTS	11,404	$45,578,800	$3,997
ASPARAGUS	25,680	$86,513,000	$3,369
BEANS/PEAS (Dry)	1,533,180	989,730,200	$646
BEANS (Snap, Bush, Pole, String)	157,464	$249,372,100	$1,584
BROCCOLI[1]	124,920	$878,913,800	$7,036
CABBAGE[1]	57,434	$401,307,200	$6,987
CANOLA	1,400,560	$469,069,600	$335
CAULIFLOWER[1]	40,976	$396,934,600	$9,687
CELERY	28,580	$376,764,000	$13,183
CHERRIES (sweet)	87,378	$786,386,200	$9,000
CHERRIES (tart)	37,070	$74,307,600	$2,005
CORN (grain)	84,655,400	$66,043,095,400	$780
COTTON	9,274,520	$6,192,680,600	$668
CRANBERRIES	39,980	$314,384,800	$7,864
CUCUMBERS (fresh market)	39,980	$191,819,200	$4,877
CUCUMBERS (processing)	39,328	$174,862,000	$2,074
GARLIC	84,324	$255,807,200	$10,514
GRAPEFRUIT	24,330	$270,440,800	$3,731
GRAPES (raisin)	72,480	$792,405,000	$3,942
GRAPES (table)	201,000	$1,200,629,600	$11,435
GRAPES (wine)	105,000	$2,887,594,600	$4,876
HAZELNUTS	592,200	$94,470,000	$3,224
LEMONS	29,300	$454,421,000	$8,268
MINT	54,960	$191,789,600	$2,080
ONIONS	92,160	$919,155,000	$6,322
ORANGES (FL)	434,460	$1,456,223,400	$3,352
ORANGES (CA)	177,444	$759,065,600	$4,278
PEACHES	83,656	$493,190,600	$5,495
PEANUTS	1,261,020	$1,269,374,000	$1,007
PEARS	51,720	$416,869,800	$8,060
PEAS (Fresh/Green/Sweet)	179,700	$138,392,200	$770
PECANS (in shell)	4,938,401	$556,737,800	$1,127

Crop	Acres Harvested (Avg. Annual)	Gross Revenue (Avg. Annual)	Gross Revenue (Avg. Annual $ per acre)
PEPPERS (bell)	45,940	$589,605,400	$12,834
PEPPERS (chile)	20,920	$163,307,000	$7,806
PISTACHIOS	179,200	$1,389,330,000	$7,753
PLUMS / PRUNES	74,800	$272,710,000	$3,646
POTATOES	1,065,580	$3,990,486,000	$3,745
PUMPKINS	49,060	$133,716,800	$2,726
SORGHUM[1]	6,104,000	$1,497,555,800	$245
SOYBEANS	77,074,800	$40,578,872,000	$526
SQUASH	41,306	$218,161,600	$5,282
STRAWBERRIES	58,551	$2,507,214,000	$42,821
SUGARBEETS[1] (Except MN and ND)	498,260	718,550,000	$1,442
SUGARBEETS[1] (MN and ND)	627,400	693,810,400	$1,106
SUNFLOWER	1,629,260	$572,820,200	$352
SWEET CORN (fresh market)	223,326	$734,824,200	$3,290
SWEET CORN (processing)	330,912	$312,695,800	$945
SWEET CORN (combined)	554,238	$1,047,520,000	$1,890
TOBACCO	346,564	$1,471,710,200	$4,247
TOMATOES (fresh market)	100,302	$1,125,381,200	$11,220
TOMATOES (processing)	283,220	$1,093,076,600	$3,859
WALNUTS	272,000	$1,520,686,000	$5,591
WATERMELON	120,988	$488,717,800	$4,039
Wheat (Spring)	13,978,000	$4,377,700,800	$313
Wheat (Winter)	32,631,000	$9,772,478,200	$299

Sources: USDA NASS, 2010 – 2014

[1] USDA NASS, 2014 – 2018